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REFRACTIVE EFFECTS IN REMOTE SENSING  
OF THE ATMOSPHERE WITH INFRARED  
TRANSMISSION SPECTROSCOPY

Donald E. Snider  
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June 1975

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for aircraft observers, 60% for high altitude balloons, and 200% for satellite observers.

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## INTRODUCTION

Our ability to predict the performance of Army systems in natural and disturbed environments depends on our understanding of the chemistry and physics of the atmosphere. In order to improve our knowledge in this area, the BRL undertook the Combined Stratospheric Measuring Program (COSMEP) in the summer of 1972. The goal of this program is to make near simultaneous measurements of stratospheric minor constituents, both charged and neutral. This report deals with one of the techniques used to obtain mixing ratio profiles for minor neutral constituents.

The use of infrared remote sensing techniques for studying atmospheric composition has increased greatly within the last decade. One of these techniques is to analyze transmission spectra of the earth's atmosphere which are made using the setting sun as a source. This technique has the advantages that 1) the long optical paths through the atmosphere increase the sensitivity of this technique to minor constituents, 2) the long paths through the atmosphere decrease the sensitivity of this technique to localized contamination, especially water vapor, and 3) the geometry associated with this technique allows the vertical mixing ratio profiles for minor constituents to be established.<sup>1,2</sup>

In order to use this technique to derive mixing ratio profiles, one must know the quantity of gas in the optical path, the so-called *air mass*. Since this quantity is so fundamental, it has been calculated by many investigators for a variety of conditions, under a variety of different assumptions.

One assumption which greatly simplifies the calculation of the air mass is that atmospheric refraction is negligible. In this case, the Chapman function<sup>3</sup> can be used to calculate the air mass, and simple geometry can be used to compute the minimum altitude for a grazing ray.

The subject of atmospheric refraction has been treated by many authors and was originally discussed by Laplace. It has been reviewed recently by Kondratyev,<sup>4</sup> and will not be reviewed here, except to the extent that it contributes to the air mass calculations.

---

<sup>1</sup> Drayson, S. R., Bartman, F. L., Kuhn, W. R. and Tallamraju, R., "Feasibility of Satellite Measurements of Stratospheric Minor Constituents by Solar Occultation," Technical Report 011023-2-T, High Altitude Engineering Laboratory, University of Michigan, Oct. 1973.

<sup>2</sup> Farmer, C. B., "Infrared Measurements of Stratospheric Composition," Can. J. Chem., 52, 1544 (1974).

<sup>3</sup> Chapman, S., "The Absorption and Dissociative or Ionizing Effect of Monochromatic Radiation in an Atmosphere on a Rotating Earth. II. Grazing Incidence," Proc. Phys. Soc. (London) 43, 483 (1931).

<sup>4</sup> Kondratyev, K. Ya., "Radiation in the Atmosphere," Academic Press, 1969.

One of the earliest tabulations of air mass which took refraction into account was performed by Bemporad,<sup>5,6</sup> and has been generally accepted by astronomers. This calculation was performed for a ground based observer and for zenith angles less than or equal to  $90^\circ$ . A closed form expression, approximating Bemporad's results to within 1.5% for zenith angles less than or equal to  $87.5^\circ$ , has been given by Nagle.

Since air mass and refraction depend on the meteorological conditions of pressure, temperature, and humidity, as well as on wavelength, one would expect that the computed air mass and refraction would vary depending on the assumed atmospheric profile. Kasten<sup>8,9</sup> has studied the effect of density variations on relative air masses. Link<sup>10,11,12</sup> has published a large number of computations, the most comprehensive of which<sup>12</sup> tabulates the refraction, air mass, and related quantities for a variety of reference atmospheres, observer and source heights, and zenith angles ( $70$  to  $90^\circ$ ). The index of refraction used in the above calculations corresponds to light with a wavelength of  $500$  nm. Formulae for correcting the tabulated refraction are given for wavelengths between  $400$  and  $700$  nm.

None of the tables described above gives the refraction and the air mass for an observer above the surface and for zenith angles greater than  $90^\circ$ , the so-called *occultation* geometry. Several investigators have filled this gap by developing computer programs to calculate refraction and air mass under specific conditions.

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<sup>5</sup> Bemporad, A., "Search for a New Empirical Formula for the Representation of the Variation of the Intensity of Solar Radiation with Zenith Angle," Rend. Acc. Lincei, 16, 66 (1907).

<sup>6</sup> List, R. J., "Smithsonian Meteorological Tables," 6th Revised Edition, 1949, Fifth Reprint, 1971, Smithsonian Publication 4014.

<sup>7</sup> Nagle, M. R., "Improved Approximation of Bemporad's Air Mass Function," Appl. Opt. 13, 1009 (1974).

<sup>8</sup> Kasten, F., "A New Table and Approximation Formula for the Relative Optical Airmass," Arch. Meteorol. Geophys. u. Bioklimatol. B14, 206 (1966).

<sup>9</sup> Kasten, F., "Effect of Variation of the Vertical Air Density Profile on the Relative Optical Air Mass," Arch. Meteorol. Geophys. u. Bioklimatol. B15, 62 (1967).

<sup>10</sup> Link, F. and Sekera, Z., "Dioptrische Tafeln der Erdatmosphäre," Publikace Prazske, Hvezdarny Prague (1940)

<sup>11</sup> Link, F., "Extension des Tables Dioptriques De L'Atmosphere Terrestre," Promethus, Prague, 1947.

<sup>12</sup> Link, F. and Neuzil, L., "Tables of Light Trajectories in the Terrestrial Atmosphere," Hermann, Paris, 1969.



Selby and McClatchey<sup>13</sup> have included refraction in their multi-purpose computer code LOWTRAN 2. This code is flexible enough to include almost any remote sensing geometry. They have defined six reference atmospheres with respect to pressure, temperature, and water vapor content. These reference atmospheres are used to compute the index of refraction as a function of altitude. They also took into account the deviation of the earth's surface from that of a sphere.

Watson and Yin<sup>14</sup> have studied the effects of refraction on solar occultation measurements of atmospheric gases. They have included anomalous dispersion,<sup>15</sup> and have computed the "infinite resolution" and instrumental line shapes for three H<sub>2</sub>O lines under a variety of atmospheric models. They formed the absorption coefficient in a line-by-line and layer-by-layer process, and therefore did not use a single layer approximation of the Curtis-Godson type.

Hymus and Lloyd,<sup>16,17</sup> and Miller<sup>18</sup> have computed the refraction and extinction of a near ultraviolet tangential ray. Since different processes govern the extinction of infrared and ultraviolet radiation, their results are not directly applicable to the IR remote sensing problem. Treve<sup>19,20</sup> has described a ray-tracing technique which can be used to compute the atmospheric refraction and air mass for a number of different source-observer geometries, and for a wavelength range of 0.2 to 20 micrometers.

<sup>13</sup> Selby, J. E. A., and McClatchey, R. A., "Atmospheric Transmittance from 0.25 to 28.5  $\mu$ m: Computer Code LOWTRAN 2," Technical Report AFCRL-72-0745, Environmental Research Paper No. 427, 29 Dec 1972.

<sup>14</sup> Watson, J. K. G. and Yin, P. K. L., "The Effects of Refraction and Dispersion on High Altitude Measurements of Atmospheric Gases," Interim Report R.F. Project 3460, The Ohio State University Research Foundation, October 1973.

<sup>15</sup> Calfee, Robert F., "Anomalous Dispersion Calculated for Atmospheric Water Vapor," Appl. Opt. 7, 1652 (1968).

<sup>16</sup> Hymus, F. C., and Lloyd, K. H., "Extinction of a Tangential Ray, by Ray Tracing Through The Atmosphere," Technical Note HSA-152, Australian Defence Scientific Service, Weapons Research Establishment, May 1969.

<sup>17</sup> Lloyd, K. H., "Absorption of a grazing Ray Calculated by Ray Tracing," Planetary and Space Sciences 17, 1683 (1969).

<sup>18</sup> Miller, D. E., "Stratospheric Attenuation in the Near Ultraviolet," Proc. Roy. Soc. A 301, 57 (1967).

<sup>19</sup> Treve, Y. M., "New Values of the Optical Air Mass and the Refraction and Comparison with Previous Tables," Technical Report ESD-TDR-64-103, Mitre Corp. 1964.

<sup>20</sup> Treve, Y. M., "A New Method for the Calculation of the Atmospheric Refraction and the Optical Air Mass," Unpublished.



This report describes a series of air mass and refraction calculations, performed using a modified and extended version of Treve's ray-tracing technique. In an attempt to assess the accuracy of this technique several checks and comparisons were performed, and are also described in this report. Finally, tables giving the refraction, air mass, and Curtis-Godson effective temperature and pressure for both a summer and winter reference atmosphere are given in Appendix A. Tables in Appendix A cover an observer altitude range of 10 to 50 km in steps of 1 km. For each altitude, the zenith angles go from 80° to 89° in steps of 1.0°, and from 89° to the disc in steps of 0.2°. A statement listing for the computer program used to generate the tables in Appendix A is given in Appendix B.

## THEORY

The technique used for these calculations is basically that of Treve, with several modifications. A brief description of that technique will be given here with a somewhat more detailed description of the modifications.<sup>19,20</sup> For more details, the reader is referred to the original descriptions.

The model assumes a dry atmosphere, which is made up of spherically symmetric concentric shells, of known temperature and pressure. The atmosphere is assumed to be an ideal gas\* in hydrostatic equilibrium. Together with the above assumptions, Snell's law can be used to derive the relation (see reference 13):

$$n_i r_i \sin z_i = \text{constant} \quad (1)$$

where:  $n_i$  is the phase refractive index of level  $i$ .  
 $r_i$  is the distance from the center of the earth to level  $i$ .  
 and  $z_i$  is the angle of incidence with respect to the local normal.

The phase refractive index for dry air is given by reference 22:

$$(n_0 - 1.0) \times 10^6 = 64.328 + 29498.1 (146 - 1/\lambda^2)^{-1} + 255.4 (41 - 1/\lambda^2)^{-1} \quad (2)$$

for a temperature of 288.16K and a pressure of 101325.0 N/m<sup>2</sup>. The wavelength  $\lambda$  is given in micrometers. This expression for the index of refraction neglects the effects of anomalous dispersion as well as the contribution of water vapor. Anomalous dispersion has been studied by Calfee,<sup>15</sup> and Watson and Yin,<sup>14</sup> and has been shown<sup>14</sup> to be negligible for stratospheric conditions. The correction to the index of refractions for water vapor has been given by Owens<sup>21</sup> and has also been determined to be small for stratospheric conditions.

\* Strictly speaking, this is not true (see Ref. 21), but to the degree of accuracy that we are interested in here, this approximation is a good one.

<sup>21</sup> Owens, James C., "Optical Refractive Index of Air: Dependence on Pressure, Temperature, and Composition," Appl. Opt. 6, 51 (1967).

<sup>22</sup> Edlen, B., "The Index of Refraction for Dry Air in the Visible and Infrared," Metrologia 2, 71 (1966).

The index of refraction for each shell was computed from Equation (2) assuming it to be a function of density alone. This dependence is given by the Lorentz-Lorenz relation:

$$\frac{1}{\rho} \left( \frac{n^2 - 1}{n^2 + 2} \right) = \text{constant} \quad (3)$$

The density  $\rho$  in this expression is obtained from the perfect gas law;

$$\rho = \frac{M P}{R^* T} \quad (4)$$

where:  $M$  is the mean molecular weight of air = 28.966,

$R^*$  is the universal gas constant = 8314.39 J/K/kg-mole,

$P$  is the pressure in  $\text{N/m}^2$ ,

and  $T$  is the temperature in K.

For the calculations performed in this study, various temperature profiles were used and the corresponding pressure profiles were computed from the following relations derived [assuming an ideal gas - Reference (23)] from the hydrostatic equation:

$$\frac{P}{P_0} = \begin{cases} \left( \frac{T_0}{T_0 + L(H - H_0)} \right)^{\frac{g_0 M}{R^* L}} & L \neq 0 \\ \exp \left[ -g_0 M \frac{(H - H_0)}{R^* T} \right] & L = 0 \end{cases}$$

where:  $P_0$  is the pressure at the base level,

$H$  is the geopotential altitude,

$H_0$  is the geopotential altitude of base,

$L$  is the gradient of temperature  $T$  with geopotential altitude  $H$ ,

and  $g_0$  is the acceleration of gravity - assumed to be a function of latitude, but not of altitude.

Since the conversion factors between geopotential and geometric altitude as well as the acceleration of gravity  $g_0$  are functions of latitude, Treve's model was extended to cover all latitudes by using the appropriate expressions given by Lambert:<sup>6,23</sup>

<sup>23</sup>U.S. Standard Atmospheric Supplements, 1966.



$$Z_{\phi}(H) \equiv \frac{r_{\phi} H}{\frac{r_{\phi} g_{\phi}}{G} - H} \quad (6)$$

$$H_{\phi}(Z) \equiv \frac{r_{\phi} Z}{r_{\phi} + Z} \cdot \frac{g_{\phi}}{G} \quad (7)$$

where:  $H_{\phi}$  = altitude in geopotential meters (m'),

$Z_{\phi}$  = altitude in geometric meters (m),

$G = 9.80665 (\text{m})^2 (\text{sec})^{-1} (\text{m}')^{-1}$ ,

$g_{\phi}$  = sea level acceleration of gravity at latitude  $\phi$ ,  $(\text{m}) (\text{sec})^{-2}$ ,

$r_{\phi}$  = effective earth radius for latitude  $\phi$ , (m),

$$g_{\phi} = 9.806160 \left\{ 1.0 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi \right\} \quad (8)$$

and

$$r_{\phi} = \frac{2 g_{\phi}}{3.085462 \times 10^{-6} + 2.27 \times 10^{-9} \cos 2\phi - 2 \times 10^{-12} \cos 4\phi} \quad (9)$$

This expression for the effective earth radius  $r_{\phi}$  is not in general equal to the radius of the earth at the given latitude. It is rather a fictitious quantity, designed to satisfy boundary conditions and to take into account the non-spherical shape of the earth, its density distribution, and centripetal acceleration.<sup>24</sup>

The geocentric radius vector to the surface of the ellipsoid, which approximates the surface of the earth, is computed from the relationship:<sup>24</sup>

$$R(\phi) = \left\{ \frac{a^4 \cos^2 \phi + b^4 \sin^2 \phi}{a^2 \cos^2 \phi + b^2 \sin^2 \phi} \right\}^{1/2} \quad (10)$$

where:  $a$  = equatorial radius = 6378.160 km

$b$  = polar radius = 6356.775 km

and  $\phi$  = latitude

<sup>24</sup> Hankey, John R., "The American Ephemeris and Nautical Almanac 1974," U.S. Government Printing Office, 1971.



The earth is here approximated as a sphere, with an effective radius  $R(\phi)$ , which depends on latitude. Table 1 shows a comparison of  $r_\phi$  and  $R(\phi)$  as a function of latitude.

TABLE 1. COMPARISON OF  $r_\phi$  AND  $R(\phi)$

Latitude	$R(\phi)$ km	$r_\phi$ km
0.0	6378.160	6334.984
30.0	6372.847	6337.838
45.0	6367.512	6356.360
60.0	6362.155	6367.103
90.0	6356.775	6377.862

For the purposes of ray tracing, it is important to use the geometric radius vector  $R(\phi)$  rather than the effective radius  $r_\phi$ . For altitudes of less than 100 km, the error in geopotential altitude  $H$  will be less than 0.01 km.

The relevant geometry for this type of calculation is shown in Figures 1 and 2.  $H_{ob}$  is the altitude of the observer in geometric meters above the earth's surface. The astronomical zenith angle ( $z$ ) is the angle between the local normal and an unrefracted ray from the source. The apparent zenith angle ( $z'$ ) is the angle of arrival of a refracted ray from the source. The refraction is the difference ( $z - z'$ ).

For the case that  $z'$  is greater than  $90^\circ$  (Figure 2) the grazing altitude (minimum height) is less than the observer height. As long as the density profile is monotonic decreasing with altitude, the minimum height for a refracted ray will always be greater than that for an unrefracted ray. From Figure 2 and simple geometric consideration, the minimum altitude for an unrefracted ray can be seen to be:

$$H_{min} = (R(\phi) + H_{ob}) \sin(\pi - z) - R(\phi) \quad (11)$$

Thus the unrefracted minimum height is a function of observer height, zenith angle, and earth radius (which is a function of latitude).

The air mass, or the quantity of atmosphere traversed by the ray, is defined as:

$$\text{air mass} \equiv \frac{1}{2.15335 \times 10^{29}} \int_{\text{Observer}}^{\text{Source}} N \, ds \quad (12)$$

where  $ds$  is the arclength along the refracted ray, and  $N$  is the number density (molecule/m<sup>3</sup>). Since the source is outside the atmosphere, integration is cut off at the height of the highest level of the assumed

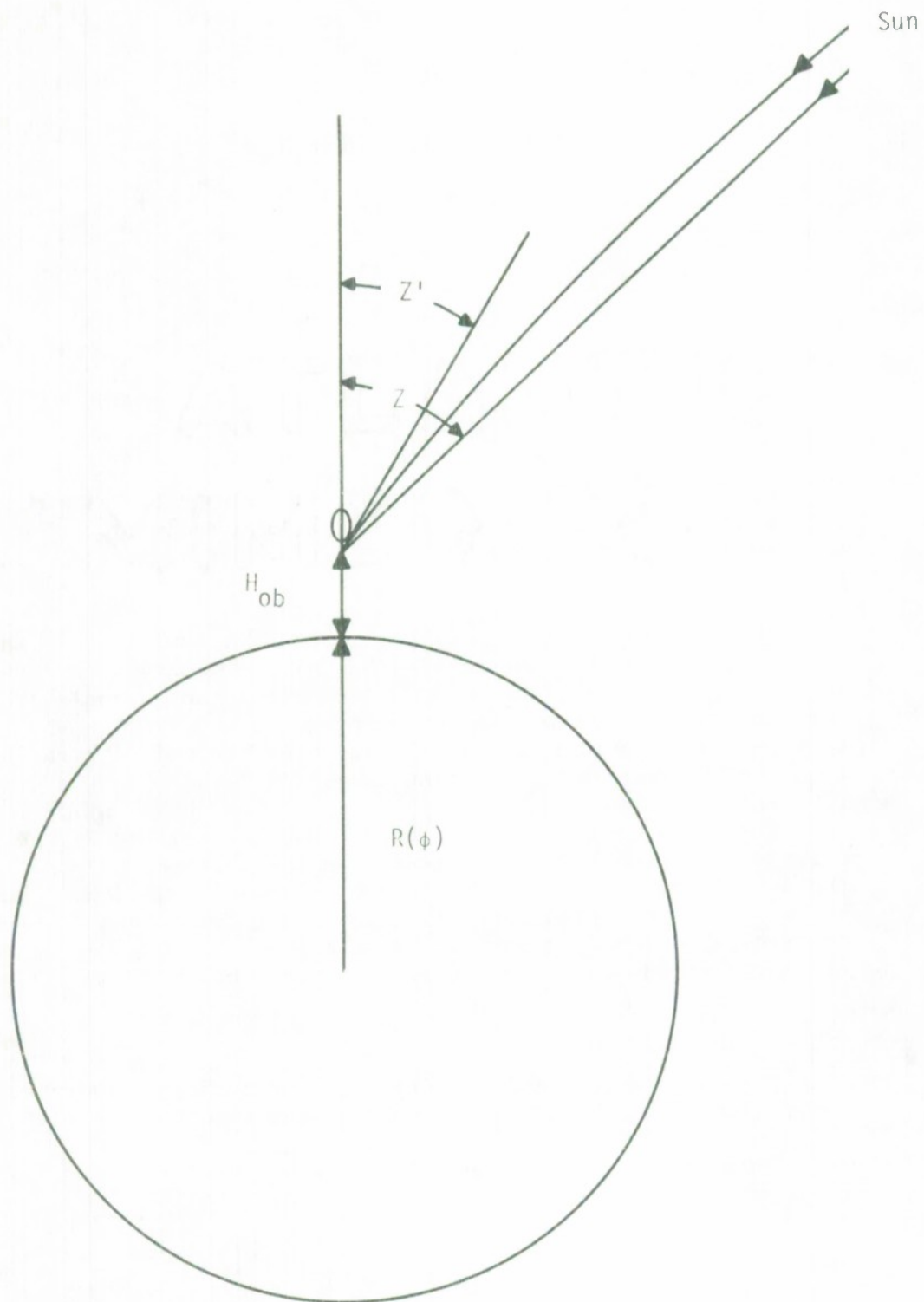


Figure 1. Refracted and unrefracted rays for zenith angles less than  $90^\circ$ .

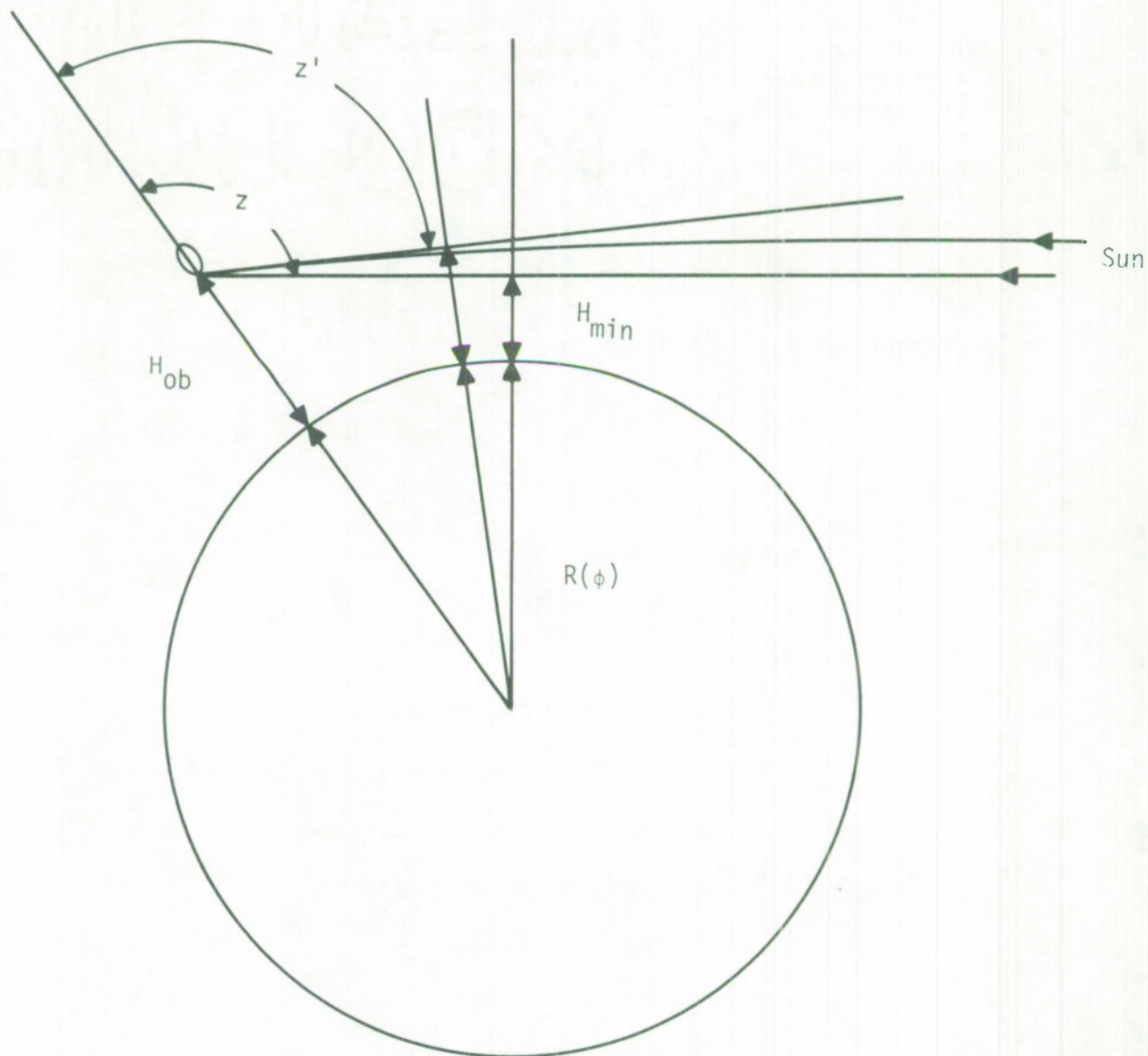


Figure 2. Refracted and unrefracted rays for zenith angles greater than  $90^\circ$ .



profile. For purposes of comparison, one standard air mass is here defined\* as  $2.15335 \times 10^{29}$  molecules/m<sup>2</sup>. This corresponds to the numerical integration of Equation (12) with  $z = 0$  between 0 and 100 km for the 1962 U.S. Standard Atmosphere. Thus the present calculation gives an absolute air mass, to which other profiles can be compared, rather than a relative air mass, as originally computed by Treve.

For the case when refraction is neglected, the air mass can be computed for large zenith angles from the Chapman function.<sup>5</sup> Simplified approximations to this function have been derived by Smith and Smith,<sup>25</sup> from expressions given by Fitzmaurice<sup>26</sup> and modified for a non-exponential atmosphere. They are given by:

$$\text{air mass} \equiv \frac{n_p H_p}{2.15335 \times 10^{29}} \text{Ch}(x_p, x_p) \equiv \frac{n_p H_p}{2.15335 \times 10^{29}} [(\pi/2) x_p]^{1/2} e^{(y^2)} \cdot \text{erfc}(y) \quad x_p \leq 90^\circ \quad (13)$$

$$\text{air mass} \equiv [(\pi/2) x_g]^{1/2} \frac{H_g}{2.15335 \times 10^{29}} [2 n_g - n_p e^{(y^2)} \cdot \text{erfc}(y)] \quad x_p > 90^\circ \quad (14)$$

Where

$n_p$  = number density at observer height,

$n_g$  = number density at unrefracted grazing height  $H_{\min}$  (Eq. 11)

$H_p$  = scale height at observer altitude,

$H_g$  = scale height at grazing altitude,

$x_p = (R(\phi) + H_{\text{ob}})/H_p$ ,

$x_g = (R(\phi) + H_{\min})/H_g$ ,

$x_p$  = astronomical zenith angle at observer,

$y = (x_p/2)^{1/2} |\cos x_p|$

and  $\text{erfc}(y) = 1.0 - \text{erf}(y)$ .

\* Note: The term air mass does not have a standard definition. Before comparing the values in this report to other work, the definitions must be compatible.

<sup>25</sup> Smith, F. L. III, and Smith, Cody, "Numerical Evaluation of Chapman's Grazing Incidence Integral  $\text{ch}(X, X)$ ," J. Geophys. Res. **77**, 3592 (1972).

<sup>26</sup> Fitzmaurice, John A., "Simplification of the Chapman Function for Atmospheric Attenuation," App. Opt. **3**, 640 (1964).



These approximations take into account the fact that the air mass is most sensitive to the scale height and density near the observer for zenith angles less than or equal to  $90^\circ$ .<sup>27</sup> For zenith angles greater than  $90^\circ$ , the air mass is most sensitive to the scale height near the grazing altitude.<sup>27</sup> For  $X = 800$  this approximation is expected to be better than 1%.

In order to compute the infrared absorption for a non-homogeneous ray path, such as used in this study, one must evaluate the absorption coefficient at each wavelength for each layer. This turns out to be a very time consuming computation.

An alternative to this procedure is to define an "equivalent" homogeneous path at an effective pressure  $P(\text{eff})$  and effective temperature  $T(\text{eff})$ , such that the calculated absorption is the same as that for the non-homogeneous case. For a uniformly mixed gas such as  $\text{CO}_2$ , Sasamori<sup>28</sup> has suggested defining these quantities as:

$$P(\text{eff}) \equiv \frac{\int_{\text{Observer}}^{\text{Source}} P \, dm}{\int_{\text{Observer}}^{\text{Source}} dm} \quad (15)$$

$$T(\text{eff}) \equiv \frac{\int_{\text{Observer}}^{\text{Source}} T \, dm}{\int_{\text{Observer}}^{\text{Source}} dm}$$

Where  $\int_{\text{Ob}}^{\text{Source}} dm$  gives the total integrated absorber mass, along the ray path. Thus the effective temperature\* and pressure are essentially mass weighted average values.

For the case that the gas in question is not uniformly distributed, the varying mixing ratios should be included inside the integrals of Equation (15). However, for the case that  $Z > 90^\circ$ , the air mass increases rapidly with a small change in zenith angle. Thus for this case, the effective pressure and temperature are most sensitive to the mixing ratio at the tangent height, since most of the air mass is located within a few kilometers of the tangent height.

\* Strictly speaking, the effective temperature depends on the intensities of the spectral lines.<sup>29</sup> For stratospheric occultation geometries, the temperature variation along a tangent ray will not be large. In this case, the mass weighted average temperature will be a good approximation to the effective temperature.

<sup>27</sup> Swider, William Jr., "The Determination of the Optical Depth at Large Solar Zenith Distances", Planet. Space Sci. **12**, 761 (1964).

<sup>28</sup> Sasamori, T., "The Temperature Effect on the Absorption of the  $15\mu$   $\text{CO}_2$  Band," Sci. Rept. Tohoku Univ. Fifth Series **11**, No. 3.

<sup>29</sup> Plass, G. N., "Spectral Band Absorptance for Atmospheric Slant Paths," Appl. Opt. **2**, 515 (1963).

## VERIFICATION OF MODEL

In order to verify the numerical integration of the ray tracing technique and the above approximations to the Chapman function, the following calculation was performed. An isothermal exponential atmosphere ( $T = 272.344^\circ\text{K}$ ) was chosen so that  $X_\infty$  would be 800.00 for an observer at 10 km. A ray trace was performed<sup>p</sup> on this atmosphere ignoring the effects of refraction ( $n_1 = 1.000000000000$ ). The Chapman function derived from the numerically integrated ray traced air mass is compared to the value calculated by Wilkes.<sup>30</sup> The value for the Smith and Smith approximation is also compared to the Wilkes value. Table 2 shows the results of these comparisons. It can be seen that the Smith and Smith approximation agrees well with the Wilkes value, which is good to three decimal places.<sup>30</sup> In all cases, the agreement is better than 1/2%. The ray tracing technique gives better results for larger zenith angles, but in all cases, the difference is less than 1/2%. This agreement gives an estimate of the error associated with the numerical techniques used to approximate the ray trace air mass integral.

In an attempt to verify the accuracy of this technique for a non-exponential atmosphere, the air mass for a ground based observer was computed for a series of zenith angles, assuming the 1962 U.S. Standard Atmosphere (58 layers between 0 and 100 km). For comparison, the same calculation was performed for the case of no refraction. The results are tabulated in Table 3. There it can be seen that inclusion of refractive effects can increase the computed air mass by up to about 10% for  $z = 90^\circ$ . This is probably an upper limit since water vapor, which was neglected in computing the effects<sup>21</sup> of refraction, would be expected to decrease the index of refraction<sup>21</sup> and hence the calculated air mass. For comparison, values obtained by other investigators are also listed in Table 3. The values given by Treve appear to be the same<sup>31</sup> as those given in the Handbook of Geophysics and Space Environments,<sup>31</sup> although no reference is given. The difference<sup>19</sup> between the values calculated in this report and those of Treve<sup>19</sup> are most likely caused by the fact that Treve used the 1959 U.S. Standard Atmosphere, which differs slightly from the 1962 U.S. Standard Atmosphere above 20 km.

The importance of the assumed profile to such refraction and air mass calculations has long been recognized.<sup>9,12</sup> Table 4 shows a comparison of air mass for six different reference atmospheres. The 1962 U.S. Standard Atmosphere (58 layers, 0 to 100 km) was taken from Reference 32, and the other five were taken from Reference 33. The air mass depends on wavelength, but this effect is small<sup>12</sup> compared to the effect of different profiles.

<sup>30</sup> Wilkes, M. V., "A Table of Chapman's Grazing Incidence Integral  $ch(X, \chi)$ ", Proc. Phys. Soc. London, B67, 304 (1954).

<sup>31</sup> Valley, S. L. "Handbook of Geophysics and Space Environment,"

<sup>32</sup> U.S. Standard Atmosphere 1962.

<sup>33</sup> McClatchey, R. A., Fenn, R. W., Selby, J. E. A., Volz, F. E., and Garing, J. S., "Optical Properties of the Atmosphere (Third Edition)," Technical Report AFCRL-72-0497, Environmental Research Paper No. 411, 24 August 1972.



TABLE 2. COMPARISON OF CHAPMAN FUNCTION EVALUATED AT SEVERAL ZENITH ANGLES

Z(°)	WILKE	SMITH AND SMITH	% DIFFERENCE	RAY TRACE	% DIFFERENCE
84	8.732	8.7001	.36	8.7705	-.44
85	10.144	10.1096	.34	10.186	-.42
86	12.051	12.0096	.34	12.1007	-.41
87	14.730	14.6807	.33	14.7899	-.37
88	18.686	18.6243	.33	18.7505	-.35
90	35.466	35.448	.15	35.5345	-.19
91	55.211	55.0456	.30	55.2560	-.08
92	96.753	96.4727	.29	96.7005	-.05

% DIFFERENCE = WILKE - CHAPMAN FUNCTION (CALC.)

WILKE

TABLE 3. AIR MASS FOR A GROUND BASED OBSERVER

(WAVELENGTH = 550 nm)

APPARENT ZENITH ANGLE*	REFRACTION*	NO REFRACTION*	HANDBOOK OF GEOPHYSICS**	TREVE**	BEMPORAD**	LINK**
81.0	6.156	6.125	-	-	6.18	-
82.0	6.856	6.814	-	-	6.88	-
83.0	7.729	7.673	-	-	7.77	7.71
84.0	8.847	8.765	-	-	8.90	-
85.0	10.316	10.193	-	-	10.39	10.27
86.0	12.316	12.122	12.32	12.32	12.44	12.26
87.0	15.163	14.829	15.17	-	15.36	15.09
88.0	19.432	18.809	19.44	-	19.79	19.35
89.0	26.265	24.982	26.27	26.27	26.96	26.35
90.0	38.104	35.135	38.11	38.11	-	38.58

\* Assumes a 1962 U.S. Standard Atmosphere

\*\* Atmospheric profile is not the same or is not given.



TABLE 4. AIR MASS\* FOR A GROUND BASED OBSERVER

(WAVELENGTH = 550 nm)

APPARENT ZENITH ANGLE	1962 U.S. STANDARD	MIDLATITUDE		SUBARCTIC		TROPICAL
		SUMMER	WINTER	SUMMER	WINTER	
81.0	6.156	6.150	6.192	6.117	6.153	6.157
82.0	6.856	6.847	6.899	6.812	6.857	6.854
83.0	7.729	7.717	7.781	7.680	7.739	7.723
84.0	8.847	8.827	8.912	8.790	8.871	8.833
85.0	10.316	10.286	10.401	10.250	10.366	10.288
86.0	12.316	12.269	12.437	12.239	12.417	12.264
87.0	15.163	15.080	15.349	15.068	15.369	15.059
88.0	19.432	19.282	19.756	19.319	19.883	19.220
89.0	26.265	25.986	26.935	26.147	27.387	25.809
90.0	38.104	37.634	39.846	38.098	41.650	37.070

\*  $1.0 \text{ Air Mass} \equiv 2.15335 \times 10^{29} \text{ Molecules/m}^2$

## RESULTS

It is a well known fact that the air mass increases rapidly with zenith angle for zenith angles greater than  $90^\circ$ . Fig. 3 shows quantitatively how rapidly the air mass increases for an observer at 45 km. It is seen that the air mass changes by 3 orders of magnitude over the range  $z = 90$  to  $z = 96$  degrees. Since the sun is not a point source, it can make a significant difference in the computed air mass whether a grazing ray comes from the top of the sun or from the bottom. This can be seen from Fig. 3 where the sun's finite angular diameter is shown for comparison. If the field of view of the spectrometer is constrained only to point somewhere on the sun, the resulting uncertainty in air mass can be large. This uncertainty is shown in Table 5 where the air mass and effective pressure are seen to vary by a factor of two over a range of  $0.4^\circ$  (the sun's angular diameter is about  $0.5^\circ$ ). This effect has nothing to do with refraction, but is mentioned in passing because it can sometimes (depending on the experiment) be the major source of error, and errors caused by neglecting refractive effects must be compared with it.

As an example of the errors introduced by neglecting refraction, Fig. 4 was computed for the above example. The air mass was computed both including refraction (Fig. 3) and neglecting refraction ( $n = 1.0000000000$ ). The ordinate of Fig. 4 is proportional to the percentage error, and the upper abscissa is the corresponding minimum height (including refraction). The observer altitude of 45 km was chosen as typical of the state of the art for high altitude balloon packages. It is seen in Fig. 4 that errors introduced by neglecting refraction (for the above geometry) are less than 10% when the minimum altitude is greater than 20 km. For minimum altitudes less than 20 km, the errors become rapidly larger. The result of neglecting refraction is to underestimate the minimum altitude, and therefore to overestimate the air mass. For a realistic atmosphere (where the density is a monotonic decreasing function with altitude), the minimum altitude computed from Equation 11 will always be less than the minimum altitude obtained by ray tracing. This causes the density at the minimum altitude ( $n_g$ ) to be overestimated, and this is the dominant term in the approximation to the Chapman function.

Since Equation 11 shows the minimum height to be a function of observer height (as well as a number of other variables), one might expect that the error in minimum height would be a function of observer altitude. Fig. 5 shows this error for 3 different observer altitudes. Fig. 6 shows the corresponding errors in the computed air masses. It is thus seen that for a given grazing altitude, the above errors are larger for observers at higher altitudes. By extending this concept to an observer in a satellite at 200 km, the errors become quite significant as seen in Fig. 7.

TABLE 5

## EXAMPLE OF POINTING ERROR

OBSERVER ALTITUDE = 45 KM

MIDLATITUDE WINTER MODEL

<u>ZENITH ANGLE</u>	<u>AIR MASS</u>	<u>EFFECTIVE PRESSURE (N/m<sup>2</sup>)</u>
95.8°	15.98	14238.72
96.0°	23.49	20909.61
96.2°	33.54	30301.77



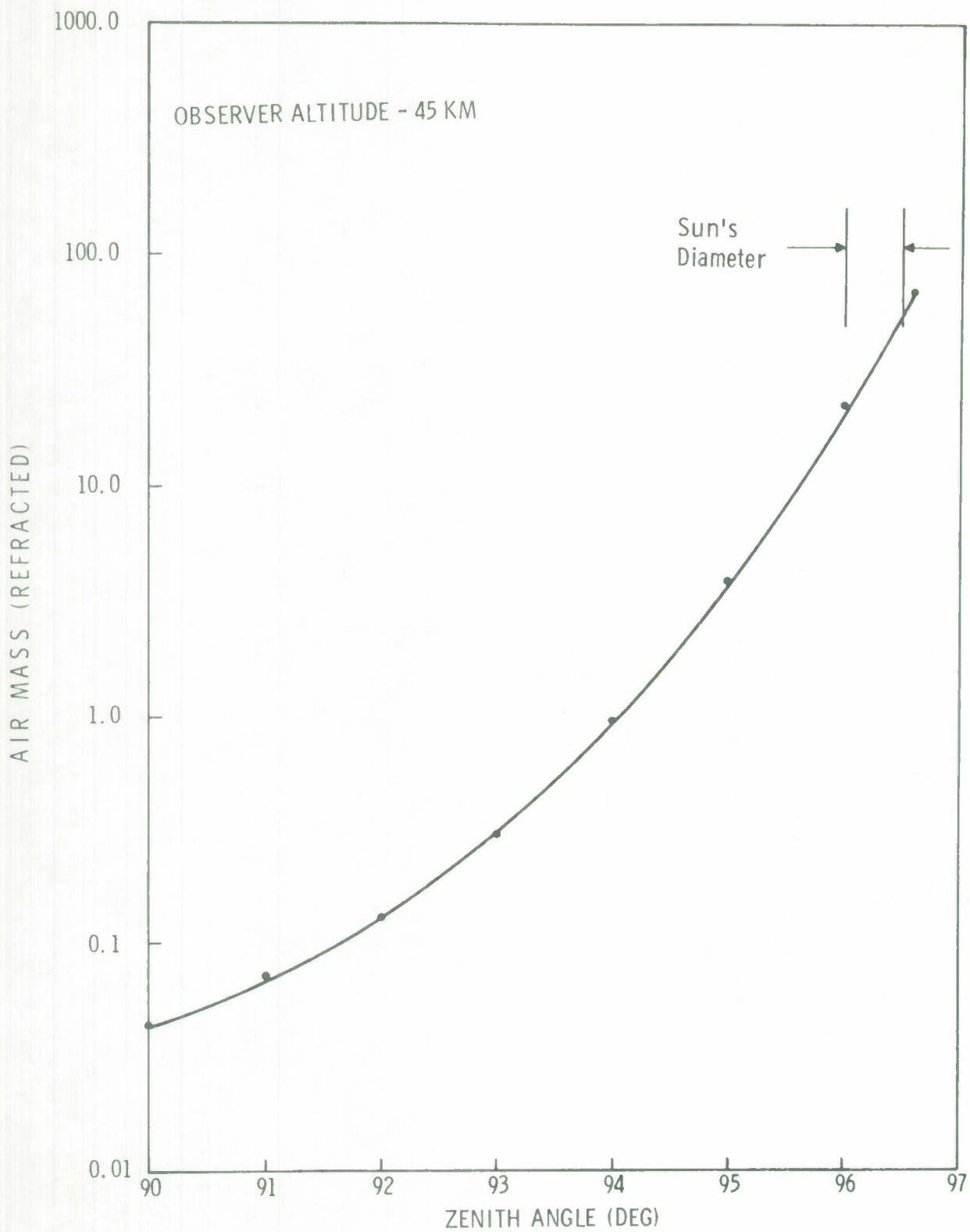


Figure 3. Air mass vs zenith angle for an observer at 45 km.

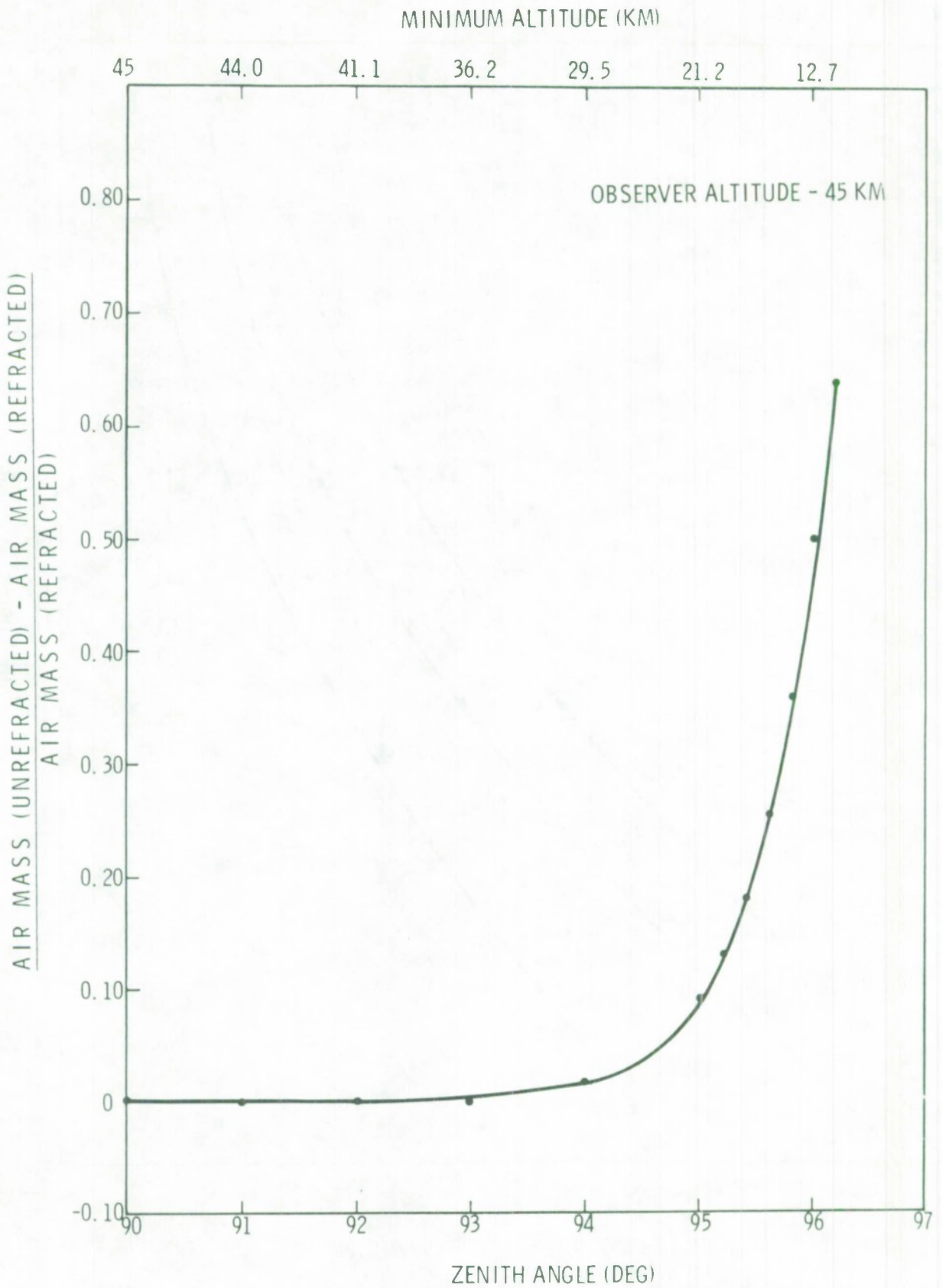


Figure 4. Air mass error due to neglecting refraction for an observer at 45 km.

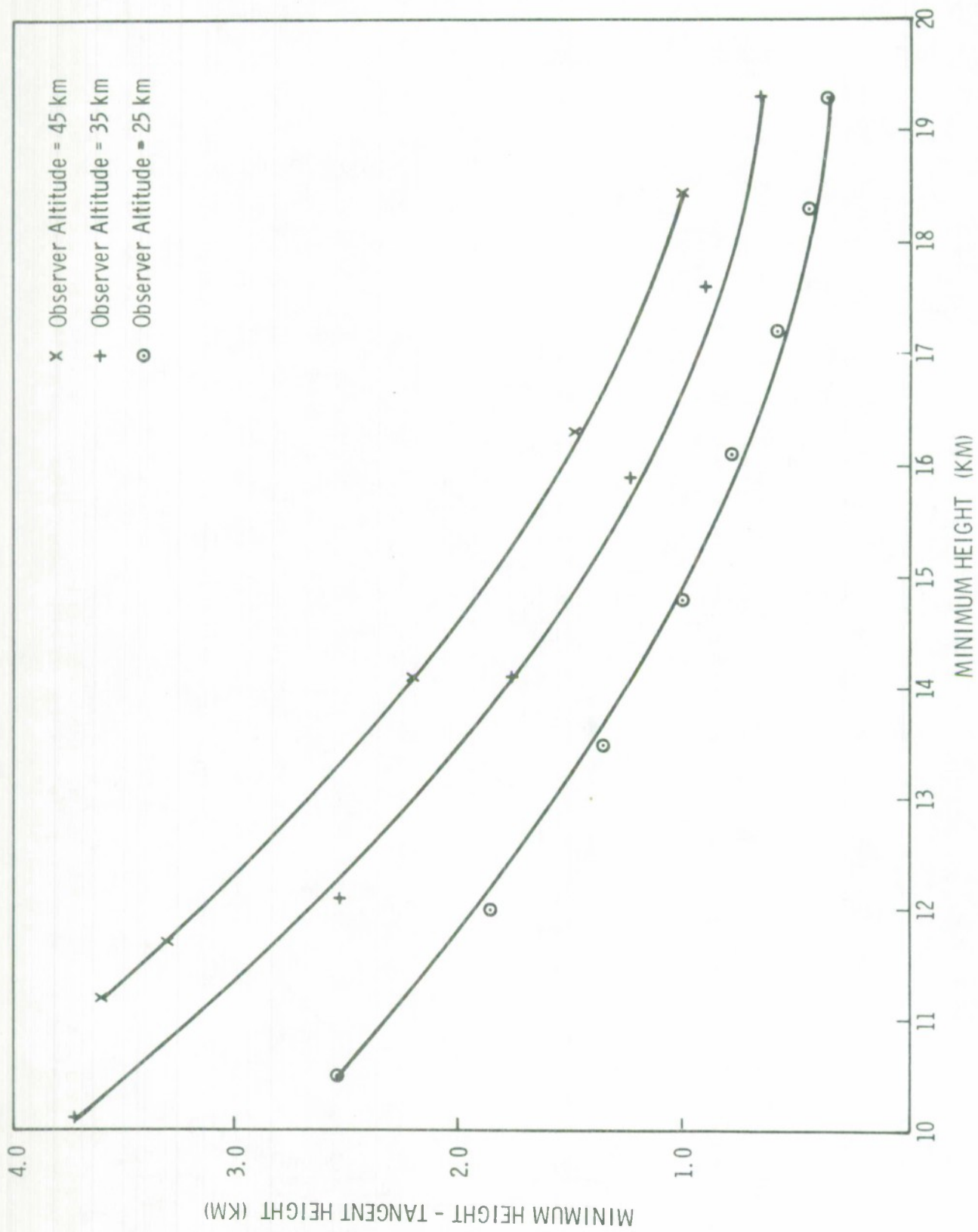


Figure 5. Error in tangent height due to refraction for observers at 25, 35, and 45 km.



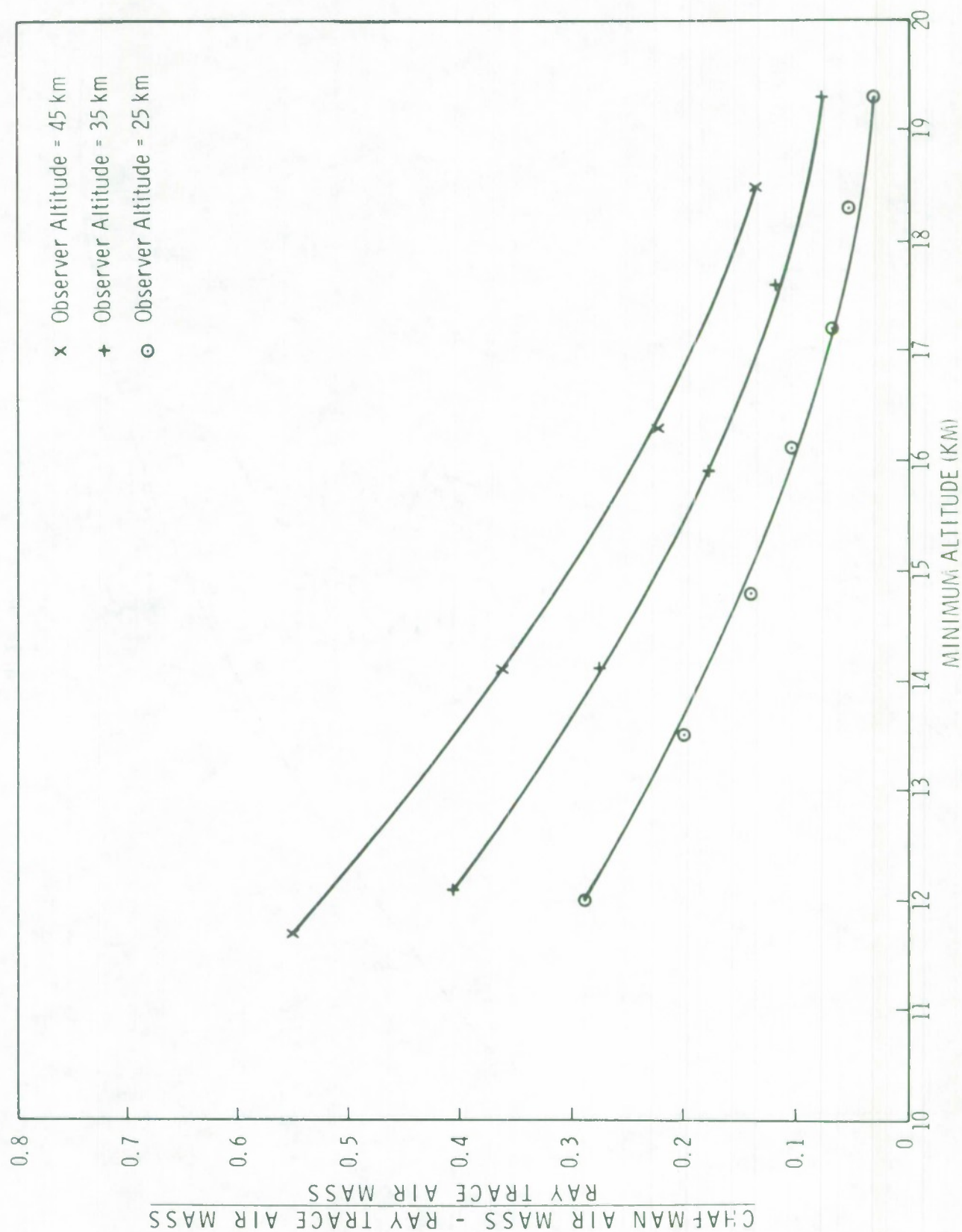


Figure 6. Error in air mass due to refraction for observers at 25, 35, and 45 km.

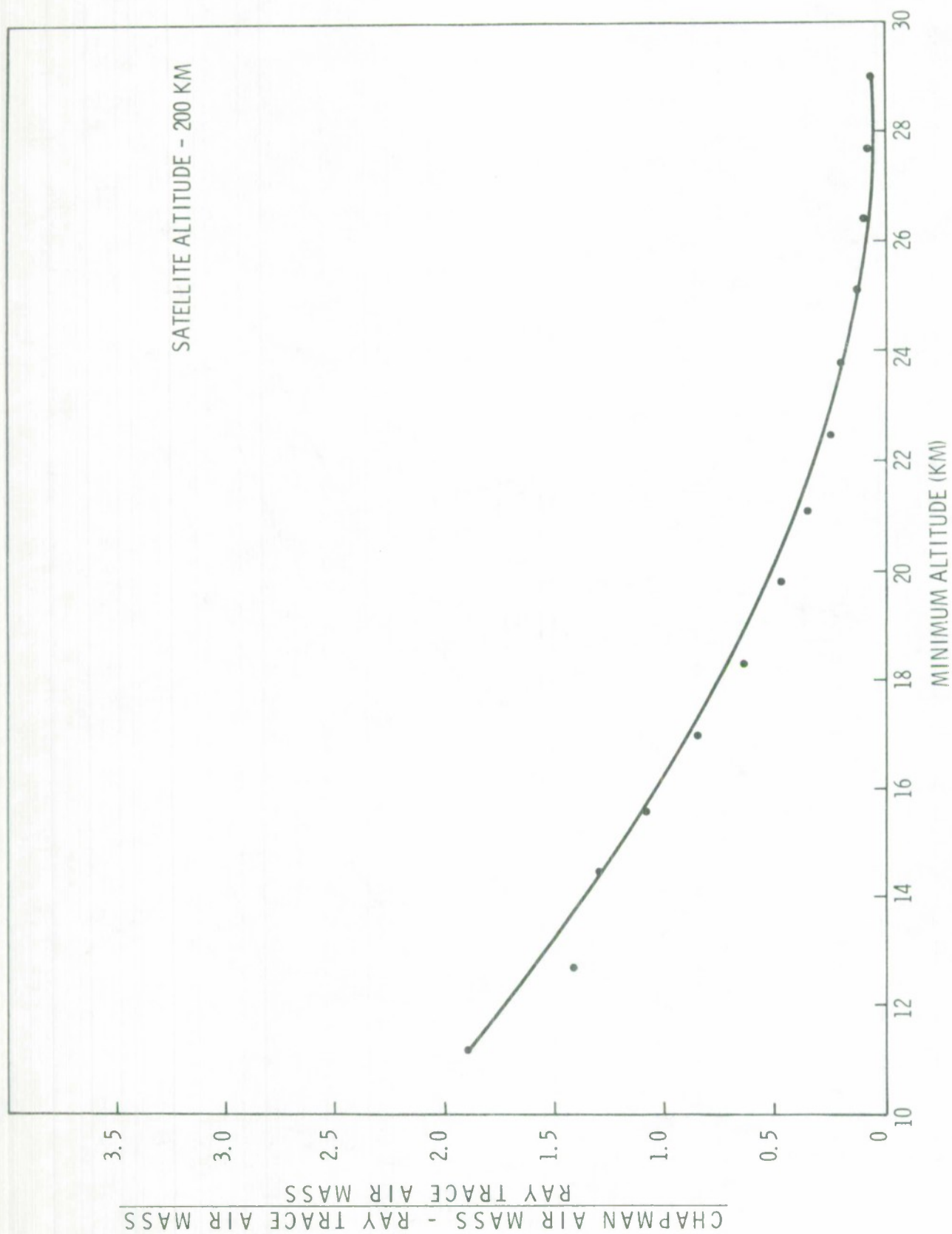


Figure 7. Error in air mass due to refraction for an observer at 200 km.

Several investigators<sup>9,12</sup> have shown that the computed air mass depends on the atmospheric profile used. Fig. 8 shows the errors that would result for an observer at 45 km, if a winter profile were used to interpret summer measurements. Although the errors are not large (compared with, for example, pointing error), they can be easily reduced by using the atmospheric profile obtained on the day of the measurement.

The sensitivity of the computed air mass with respect to wavelength errors was investigated by computing the air mass for an observer at 45 km, at both 5 and 0.5 micrometers. Even for the minimum altitude of less than 10 km, the difference in computed air mass was less than 0.4%, and the difference in minimum altitude was 19.4 meters. That the air mass is not a sensitive function to small changes in refractive index is consistent with the neglect of the contribution of water vapor and anomalous dispersion to the index of refraction.

Differential refraction,<sup>16,18</sup> which has been studied by several investigators, has not been included here. It is expected to be small for balloon altitudes, but might possibly be significant at satellite altitudes.

#### SUMMARY

Effects due to refraction have been investigated for several representative occultation geometries. Errors in the computed air mass and effective pressure, associated with neglecting refraction are shown to be a function of observer altitude. For observers in high-altitude aircraft, the errors introduced by neglecting refraction are probably less than those introduced by uncertainties in solar pointing. For observations from high altitude balloons or satellites, refraction should definitely be taken into account when the minimum altitude is less than 20 km. For all cases, accurate knowledge of the astronomical zenith angle is a necessity.

For interpretation of infrared transmission spectra, where the absorption is pressure dependent, errors in minimum altitude are doubly important. Not only will the air mass be overestimated but also the effective pressure will be overestimated. By neglecting refraction, the mixing ratios for minor constituents in the lower stratosphere would tend to be underestimated.

#### ACKNOWLEDGEMENTS

The authors are indebted to Yvon Treve, whose model served as a basis for the computations performed here, and who generously supplied unpublished material. R. Gast and R. Harter of AFCRL who supplied a FORTRAN program based on Treve's model are also gratefully acknowledged.



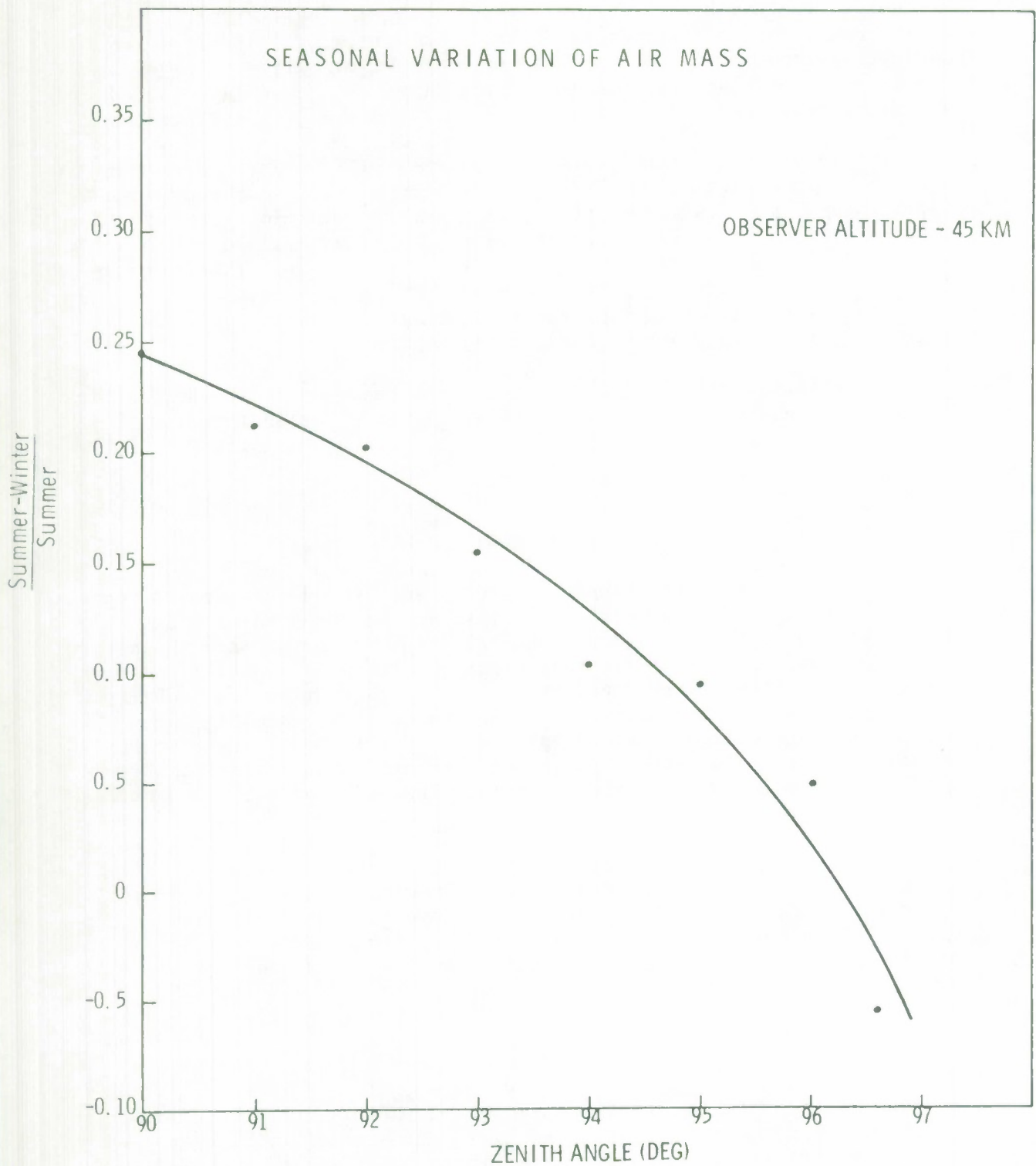


Figure 8. Error in air mass due to use of the wrong atmospheric profile.

## APPENDIX A. AIR MASS TABLES

In order to present the results of this research in a form that would be convenient for other investigators, a series of refraction air mass tables was generated. Two atmospheric models were assumed: a midlatitude summer and a midlatitude winter. Other models could have easily been included, but these two were judged adequate for most applications.

The temperature profiles and the surface pressures are those of McClatchey *et al.*<sup>53</sup> The pressure profile is calculated from the temperature profile and the surface pressure by integrating the hydrostatic equation. These calculated pressures agree to within 2% of those of McClatchey, up to 30 km. The layer thickness is 250 m up to 40 km, 1000 m up to 70 km, and 5000 m up to 100 km. There are thus 197 layers in these model atmospheres.

Tables are given for observer altitudes between 10 and 50 km, in steps of 1 km. For each observer altitude, the zenith angles range from 80° to 89° in steps of 1°, and from 89° to the solid earth in steps of 0.2°. A single wavelength of 5.0 micrometers was chosen, since the air mass is not strongly wavelength dependent.

The first column, labeled APP. Z, represents the angle of arrival (deg) with respect to the local normal. Columns 2 and 3 represent the observer height (m) and the highest level (m) included in the atmospheric profile respectively. The minimum height (m) in column 4 represents the observer altitude for  $z$  less than or equal to 90°, and the tangent altitude for a grazing ray, for  $z$  greater than 90°. Columns 5 and 6 give the air mass from the Smith and Smith approximation to the Chapman function, and the ray tracing numerical integration, respectively. In these two columns, 1.0 air masses is defined as  $2.15335 \times 10^{29}$  molecules/m<sup>2</sup>. HDIFF (m) represents the difference between the ray traced minimum altitude, and that obtained from Equation (11), neglecting refraction. Columns 8 and 9 give the refraction (deg) and the astronomical zenith angle (deg). Columns 1 and 8 add to give column 9. The single layer effective pressure  $P$  (N/m<sup>2</sup>) and temperature  $T$  (°K) for a uniformly mixed gas are given in columns 10 and 11 respectively. Column 12 gives the pressure at the tangent or minimum altitude  $P_{\tan}$  (N/m<sup>2</sup>).





AIR MASS TABLES FOR SUMMER PROFILE

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) I (10)	TIEFF I (11)	PITAN (12)
81.000	10000.0	99000.0	10000.0	1.714	1.728	.0	.03251	81.03	14609.79	222.93	28279.63
82.000	10000.0	99000.0	10000.0	1.909	1.926	.0	.03630	82.04	14668.30	222.93	28279.63
83.000	10000.0	99000.0	10000.0	2.154	2.173	.0	.04102	83.04	14748.39	222.92	28279.63
84.000	10000.0	99000.0	10000.0	2.467	2.489	.0	.04764	84.05	14861.45	222.93	28279.63
85.000	10000.0	99000.0	10000.0	2.879	2.906	.0	.05493	85.05	15027.01	222.95	28279.63
86.000	10000.0	99000.0	10000.0	3.445	3.477	.0	.06565	86.07	15260.19	222.99	28279.63
87.000	10000.0	99000.0	10000.0	4.257	4.296	.0	.08086	87.08	15688.00	223.13	28279.63
88.000	10000.0	99000.0	10000.0	5.499	5.538	.0	.10355	88.10	16387.00	223.48	28279.63
89.200	10000.0	99000.0	10000.0	8.138	8.120	.0	.14958	89.35	18056.30	224.78	28279.63
89.400	10000.0	99000.0	10000.0	8.796	8.747	.0	.16074	89.56	18493.36	225.19	28279.63
89.600	10000.0	99000.0	10000.0	9.550	9.456	.0	.17352	89.77	18998.53	225.69	28279.63
89.800	10000.0	99000.0	10000.0	10.421	10.261	.0	.18837	89.99	19582.40	226.28	28279.63
90.000	10000.0	99000.0	10000.0	11.388	11.184	41.1	.20579	90.21	20250.22	226.95	28379.44
90.200	10000.0	99000.0	9960.5	12.400	12.096	111.7	.19455	90.39	20976.66	228.21	28823.86
90.400	10000.0	99000.0	9842.2	13.573	13.131	175.5	.18584	90.59	21735.64	229.89	29577.93
90.600	10000.0	99000.0	9636.9	15.330	14.539	306.1	.23033	90.83	22795.24	231.89	31017.23
90.800	10000.0	99000.0	9338.8	17.069	16.194	460.5	.27464	91.07	24076.00	233.36	33071.72
91.000	10000.0	99000.0	8956.9	19.204	17.956	562.0	.28530	91.29	25753.65	234.73	35355.40
91.200	10000.0	99000.0	8500.3	21.617	20.027	757.9	.32457	91.52	27271.96	238.03	38669.13
91.400	10000.0	99000.0	7944.7	24.673	22.412	884.3	.33970	91.74	29691.44	239.99	42378.98
91.600	10000.0	99000.0	7313.1	28.759	25.326	1215.8	.40451	92.00	32098.50	244.11	48113.31
91.800	10000.0	99000.0	6593.4	32.959	28.529	1427.4	.43097	92.23	35165.07	248.03	54251.98
92.000	10000.0	99000.0	5778.5	37.412	32.168	1534.7	.43452	92.43	38648.21	251.84	60949.92
92.200	10000.0	99000.0	4862.7	44.393	36.984	1991.2	.50927	92.71	43286.50	256.07	72186.35
92.400	10000.0	99000.0	3857.2	53.531	42.552	2450.4	.57467	92.97	48662.43	261.13	85968.41

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS

ALL TEMPERATURES ARE IN DEGREES KELVIN

ALL PRESSURES ARE IN N/SQ M

THE APPARENT AND ASTRONOMIC ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	11000.0	99000.0	11000.0	1.482	1.495	.0	.02887	81.03	12629.92	220.97	24440.97
82.000	11000.0	99000.0	11000.0	1.652	1.666	.0	.03225	82.03	12680.62	220.95	24440.97
83.000	11000.0	99000.0	11000.0	1.863	1.880	.0	.03645	83.04	12750.01	220.92	24440.97
84.000	11000.0	99000.0	11000.0	2.135	2.153	.0	.04181	84.04	12847.96	220.89	24440.97
85.000	11000.0	99000.0	11000.0	2.493	2.515	.0	.04885	85.05	12991.37	220.85	24440.97
86.000	11000.0	99000.0	11000.0	2.984	3.010	.0	.05844	86.06	13210.67	220.81	24440.97
87.000	11000.0	99000.0	11000.0	3.690	3.720	.0	.07207	87.07	13563.94	220.80	24440.97
88.000	11000.0	99000.0	11000.0	4.771	4.800	.0	.09250	88.09	14169.65	220.89	24440.97
89.200	11000.0	99000.0	11000.0	7.074	7.056	.0	.13408	89.33	15617.87	221.58	24440.97
89.400	11000.0	99000.0	11000.0	7.648	7.605	.0	.14415	89.54	15997.48	221.84	24440.97
89.600	11000.0	99000.0	11000.0	8.305	8.227	.0	.15567	89.76	16436.51	222.18	24440.97
89.800	11000.0	99000.0	11000.0	9.265	8.935	.0	.16905	89.97	16944.19	222.60	24440.97
90.000	11000.0	99000.0	11000.0	9.899	9.747	33.2	.18478	90.18	17525.08	223.09	24489.53
90.200	11000.0	99000.0	10960.2	10.613	10.577	99.4	.17848	90.38	18176.57	224.13	24869.81
90.400	11000.0	99000.0	10840.9	11.879	11.522	161.5	.17450	90.57	18852.11	225.54	25537.79
90.600	11000.0	99000.0	10635.6	13.471	12.763	277.5	.21288	90.81	19773.94	227.16	26762.12
90.800	11000.0	99000.0	10339.7	14.835	14.225	414.2	.25169	91.05	20895.40	228.34	28513.41
91.000	11000.0	99000.0	9960.8	16.675	15.788	497.8	.25785	91.26	22376.70	229.46	30443.91
91.200	11000.0	99000.0	9509.5	18.781	17.592	666.6	.29013	91.49	23702.79	232.91	33233.24
91.400	11000.0	99000.0	8957.0	21.666	19.773	814.8	.31517	91.72	25861.07	234.75	36610.86
91.600	11000.0	99000.0	8328.3	24.993	22.359	1096.8	.36962	91.97	27992.61	238.44	41418.38
91.800	11000.0	99000.0	7616.9	28.439	25.158	1248.1	.38349	92.18	30700.40	242.39	46431.48
92.000	11000.0	99000.0	6806.7	32.554	28.484	1387.6	.39697	92.40	33824.46	246.08	52520.35
92.200	11000.0	99000.0	5895.2	39.160	32.798	1822.8	.46983	92.67	37954.90	250.28	62240.28
92.400	11000.0	99000.0	4902.8	46.542	37.798	2258.1	.53295	92.93	42756.22	255.24	74176.91
92.600	11000.0	99000.0	3816.3	55.890	43.570	2644.3	.58102	93.18	48361.11	260.95	88380.39

UNREFRACTED RAY STRIKES DISC



ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
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81.000	12000.0	99000.0	12000.0	1.277	1.288	.0	.02568	81.03	10875.41	219.63	21044.10
82.000	12000.0	99000.0	12000.0	1.423	1.436	.0	.02869	82.03	10919.25	219.59	21044.10
83.000	12000.0	99000.0	12000.0	1.636	1.620	.0	.03244	83.03	10979.24	219.54	21044.10
84.000	12000.0	99000.0	12000.0	1.840	1.856	.0	.03723	84.04	11063.92	219.47	21044.10
85.000	12000.0	99000.0	12000.0	2.149	2.167	.0	.04353	85.04	11187.89	219.38	21044.10
86.000	12000.0	99000.0	12000.0	2.574	2.594	.0	.05214	86.05	11377.45	219.26	21044.10
87.000	12000.0	99000.0	12000.0	3.185	3.208	.0	.06444	87.06	11682.84	219.11	21044.10
88.000	12000.0	99000.0	12000.0	4.122	4.143	.0	.08301	88.08	12206.77	218.96	21044.10
89.200	12000.0	99000.0	12000.0	6.122	6.107	.0	.12131	89.32	13461.79	218.96	21044.10
89.400	12000.0	99000.0	12000.0	6.621	6.587	.0	.13062	89.53	13791.35	219.03	21044.10
89.600	12000.0	99000.0	12000.0	7.193	7.133	.0	.14125	89.74	14172.72	219.14	21044.10
89.800	12000.0	99000.0	12000.0	7.854	7.756	.0	.15354	89.95	14614.00	219.30	21044.10
90.000	12000.0	99000.0	12000.0	8.568	8.471	27.4	.16789	90.17	15119.06	219.50	21057.34
90.200	12000.0	99000.0	11960.6	9.356	9.199	85.6	.15867	90.36	15683.90	220.36	21366.21
90.400	12000.0	99000.0	11842.5	10.272	10.025	138.0	.15147	90.55	16267.56	221.61	21919.67
90.600	12000.0	99000.0	11639.2	11.568	11.112	241.7	.18746	90.79	17069.07	223.09	22950.04
90.800	12000.0	99000.0	11345.7	13.174	12.400	364.5	.22402	91.02	18049.18	224.05	24424.00
91.000	12000.0	99000.0	10968.7	14.540	13.818	454.8	.23674	91.24	19362.66	224.93	26159.54
91.200	12000.0	99000.0	10517.8	16.308	15.429	601.7	.26449	91.46	20531.13	227.87	28551.02
91.400	12000.0	99000.0	9969.2	18.759	17.381	733.5	.28680	91.69	22442.18	229.37	31440.34
91.600	12000.0	99000.0	9347.9	21.642	19.621	967.5	.33018	91.93	24308.36	233.21	35426.35
91.800	12000.0	99000.0	8638.1	24.690	22.172	1126.0	.34927	92.15	26723.30	236.79	39884.28
92.000	12000.0	99000.0	7834.1	28.165	25.139	1224.8	.35558	92.36	29501.01	240.18	44989.76
92.200	12000.0	99000.0	6935.5	34.572	29.017	1671.6	.43325	92.63	33177.01	244.51	53575.04
92.400	12000.0	99000.0	5947.5	40.580	33.507	2093.8	.49581	92.90	37456.72	249.43	63998.08
92.600	12000.0	99000.0	4870.4	48.503	38.670	2436.5	.53809	93.14	42462.95	254.96	76077.59
92.800	12000.0	99000.0	3697.1	60.370	45.193	3116.6	.62871	93.43	48924.59	261.46	94714.15

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	MOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	13000.0	99000.0	13000.0	1.095	1.105	.0	.02265	81.02	9320.36	219.22	18032.34
82.000	13000.0	99000.0	13000.0	1.221	1.231	.0	.02531	82.03	9358.14	219.17	18032.34
83.000	13000.0	99000.0	13000.0	1.378	1.389	.0	.02863	83.03	9409.83	219.10	18032.34
84.000	13000.0	99000.0	13000.0	1.579	1.591	.0	.03287	84.03	9482.78	219.00	18032.34
85.000	13000.0	99000.0	13000.0	1.845	1.859	.0	.03846	85.04	9589.54	218.88	18032.34
86.000	13000.0	99000.0	13000.0	2.211	2.225	.0	.04612	86.05	9752.75	218.71	18032.34
87.000	13000.0	99000.0	13000.0	2.738	2.751	.0	.05711	87.06	10015.65	218.47	18032.34
88.000	13000.0	99000.0	13000.0	3.548	3.554	.0	.07386	88.07	10466.77	218.13	18032.34
89.200	13000.0	99000.0	13000.0	5.284	5.248	.0	.10914	89.31	11549.19	217.59	18032.34
89.400	13000.0	99000.0	13000.0	5.718	5.665	.0	.11782	89.52	11833.94	217.49	18032.34
89.600	13000.0	99000.0	13000.0	6.216	6.140	.0	.12769	89.73	12163.67	217.38	18032.34
89.800	13000.0	99000.0	13000.0	6.791	6.683	.0	.13898	89.94	12545.33	217.27	18032.34
90.000	13000.0	99000.0	13000.0	7.674	7.308	22.4	.15198	90.15	12982.13	217.17	18006.61
90.200	13000.0	99000.0	12960.4	8.108	7.963	77.2	.14676	90.35	13483.46	217.63	18283.04
90.400	13000.0	99000.0	12841.5	8.931	8.710	128.2	.14322	90.54	13997.86	218.42	18770.28
90.600	13000.0	99000.0	12638.1	10.068	9.668	220.2	.17396	90.77	14691.71	219.36	19646.08
90.800	13000.0	99000.0	12346.5	11.437	10.803	328.8	.20536	91.01	15545.19	219.86	20896.80
91.000	13000.0	99000.0	11972.0	12.562	12.060	404.6	.21416	91.21	16698.81	220.34	22372.56
91.200	13000.0	99000.0	11525.6	14.386	13.459	529.0	.23584	91.44	17712.85	223.31	24367.69
91.400	13000.0	99000.0	10980.1	16.328	15.222	673.6	.26488	91.66	19402.19	224.61	26963.50
91.600	13000.0	99000.0	10360.7	18.732	17.215	871.9	.30090	91.90	21048.87	227.92	30329.96
91.800	13000.0	99000.0	9658.0	21.306	19.444	979.6	.30889	92.11	23171.60	231.45	33997.94
92.000	13000.0	99000.0	8856.7	24.611	22.190	1146.2	.33318	92.33	25663.08	234.61	38838.13
92.200	13000.0	99000.0	7963.9	29.610	25.644	1531.6	.39988	92.60	28922.47	238.58	46047.06
92.400	13000.0	99000.0	6986.6	35.906	29.672	1966.7	.46588	92.87	32731.28	243.69	55275.19
92.600	13000.0	99000.0	5918.3	42.177	34.261	2249.4	.49906	93.10	37184.90	249.06	65465.32
92.800	13000.0	99000.0	4760.2	50.422	39.683	2543.5	.53156	93.33	42430.43	255.40	78086.20

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	PITAN) (12)
81.000	14000.0	99000.0	14000.0	.935	.944	.0	.01935	81.02	7956.89	219.78	15386.52
82.000	14000.0	99000.0	14000.0	1.042	1.052	.0	.02162	82.02	7989.33	219.73	15386.52
83.000	14000.0	99000.0	14000.0	1.177	1.186	.0	.02445	83.02	8033.69	219.65	15386.52
84.000	14000.0	99000.0	14000.0	1.349	1.359	.0	.02807	84.03	8096.27	219.55	15386.52
85.000	14000.0	99000.0	14000.0	1.577	1.587	.0	.03284	85.03	8187.81	219.41	15386.52
86.000	14000.0	99000.0	14000.0	1.890	1.900	.0	.03937	86.04	8327.64	219.22	15386.52
87.000	14000.0	99000.0	14000.0	2.342	2.348	.0	.04875	87.05	8552.66	218.95	15386.52
88.000	14000.0	99000.0	14000.0	3.038	3.032	.0	.06302	88.06	8938.25	218.56	15386.52
89.000	14000.0	99000.0	14000.0	4.528	4.472	.0	.09301	89.29	9861.43	217.93	15386.52
89.400	14000.0	99000.0	14000.0	4.900	4.826	.0	.10038	89.50	10103.89	217.80	15386.52
89.600	14000.0	99000.0	14000.0	5.328	5.228	.0	.10875	89.71	10384.47	217.68	15386.52
89.800	14000.0	99000.0	14000.0	5.820	5.688	.0	.11832	89.92	10709.00	217.55	15386.52
90.000	14000.0	99000.0	14000.0	6.332	6.217	16.3	.12931	90.13	11080.12	217.42	15347.01
90.200	14000.0	99000.0	13958.8	7.005	6.828	72.5	.14203	90.34	11541.70	217.29	15588.09
90.400	14000.0	99000.0	13835.2	7.801	7.541	136.5	.15684	90.56	12013.02	217.16	16060.46
90.600	14000.0	99000.0	13628.8	8.751	8.376	211.4	.17420	90.77	12604.99	217.04	16793.69
90.800	14000.0	99000.0	13335.1	9.901	9.363	300.8	.19472	90.99	13339.82	216.92	17834.43
91.000	14000.0	99000.0	12967.0	10.916	10.477	368.3	.20074	91.20	14350.99	216.90	19104.06
91.200	14000.0	99000.0	12525.2	12.524	11.740	484.5	.22163	91.42	15240.75	219.10	20839.16
91.400	14000.0	99000.0	11978.5	14.117	13.299	600.2	.24240	91.64	16727.65	219.90	23015.77
91.600	14000.0	99000.0	11364.6	16.217	15.042	773.9	.27296	91.87	18166.04	223.22	25869.10
91.800	14000.0	99000.0	10663.4	18.502	17.069	893.2	.28622	92.09	20050.77	226.32	29145.48
92.000	14000.0	99000.0	9868.2	21.313	19.500	1009.7	.30013	92.30	22250.98	229.13	33162.13
92.200	14000.0	99000.0	8982.9	25.818	22.614	1426.8	.37506	92.58	25146.80	233.20	39649.76
92.400	14000.0	99000.0	8010.6	31.514	26.297	1879.2	.44557	92.85	28276.84	237.87	47900.12
92.600	14000.0	99000.0	6952.6	36.655	30.316	2070.5	.46319	93.06	32494.90	243.30	56263.10
92.800	14000.0	99000.0	5853.5	43.724	35.165	2322.5	.49019	93.29	37178.44	249.45	66990.47
93.000	14000.0	99000.0	4544.3	56.716	41.786	3271.6	.61923	93.62	43415.08	256.17	87336.74

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (IEFF) (10)	T (IEFF) (11)	P (TAN) (12)
81.000	15000.0	99000.0	15000.0	.798	.806	.0	.01653	81.02	6792.88	220.45	13135.80
82.000	15000.0	99000.0	15000.0	.890	.898	.0	.01847	82.02	6820.73	220.39	13135.80
83.000	15000.0	99000.0	15000.0	1.024	1.013	.0	.02088	83.02	6858.81	220.31	13135.80
84.000	15000.0	99000.0	15000.0	1.151	1.161	.0	.02397	84.02	6912.50	220.19	13135.80
85.000	15000.0	99000.0	15000.0	1.345	1.355	.0	.02805	85.03	6990.98	220.04	13135.80
86.000	15000.0	99000.0	15000.0	1.612	1.622	.0	.03362	86.03	7110.79	219.83	13135.80
87.000	15000.0	99000.0	15000.0	1.996	2.004	.0	.04162	87.04	7303.40	219.52	13135.80
88.000	15000.0	99000.0	15000.0	2.587	2.587	.0	.05379	88.05	7633.04	219.09	13135.80
89.200	15000.0	99000.0	15000.0	3.846	3.811	.0	.07932	89.28	8420.64	218.35	13135.80
89.400	15000.0	99000.0	15000.0	4.160	4.112	.0	.08558	89.49	8627.19	218.20	13135.80
89.600	15000.0	99000.0	15000.0	4.519	4.453	.0	.09268	89.69	8866.07	218.05	13135.80
89.800	15000.0	99000.0	15000.0	4.932	4.844	.0	.10080	89.90	9142.18	217.89	13135.80
90.000	15000.0	99000.0	15000.0	5.351	5.292	11.8	.11012	90.11	9457.73	217.73	13083.16
90.200	15000.0	99000.0	14959.2	5.912	5.810	59.3	.12088	90.32	9849.99	217.58	13269.64
90.400	15000.0	99000.0	14836.6	6.571	6.412	113.2	.13340	90.53	10250.53	217.42	13645.25
90.600	15000.0	99000.0	14632.0	7.359	7.118	176.0	.14805	90.75	10753.77	217.27	14239.88
90.800	15000.0	99000.0	14345.0	8.305	7.949	250.9	.16534	90.97	11378.09	217.12	15081.40
91.000	15000.0	99000.0	13974.9	9.459	8.938	342.0	.18589	91.19	12253.12	216.99	16228.21
91.200	15000.0	99000.0	13520.9	10.887	10.124	454.9	.21055	91.41	13047.30	216.86	17756.63
91.400	15000.0	99000.0	12982.4	12.295	11.517	555.5	.22699	91.63	14354.27	216.77	19618.78
91.600	15000.0	99000.0	12369.6	14.056	13.683	705.2	.25245	91.85	15621.15	219.13	22051.19
91.800	15000.0	99000.0	11674.3	15.993	14.861	782.6	.25588	92.06	17273.14	221.92	24758.62
92.000	15000.0	99000.0	10882.4	18.567	17.075	939.2	.28091	92.28	19227.19	224.35	28442.19
92.200	15000.0	99000.0	10001.8	22.694	19.914	1374.4	.36057	92.56	21567.86	227.90	34237.84
92.400	15000.0	99000.0	9040.8	27.066	23.047	1667.7	.40130	92.80	24536.87	232.64	40637.23
92.600	15000.0	99000.0	7985.1	32.373	26.785	1937.2	.43500	93.03	28323.17	237.50	48427.22
92.800	15000.0	99000.0	6847.1	37.892	31.067	2120.2	.45125	93.25	32479.94	243.64	57369.22
93.000	15000.0	99000.0	5604.2	48.097	36.811	2877.4	.55378	93.55	37978.95	250.41	73450.83
93.200	15000.0	99000.0	4246.3	62.786	43.998	3812.0	.67160	93.87	45056.89	257.05	96338.30

UNREFRACTED RAY STRIKES DISC

## REFRACT (ON AIRMASS TABLES

## M (LATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMIC (AL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M (N) HEIGHT (4)	CHAPMAN AIR MASS (5)	OPT (CAL AIR MASS (6)	MO (FF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (ATAN) (12)
81.000	16000.0	99000.0	16000.0	.681	.689	.0	.01412	81.01	5799.13	221.24	11214.32
82.000	16000.0	99000.0	16000.0	.759	.768	.0	.01578	82.02	5823.05	221.17	11214.32
83.000	16000.0	99000.0	16000.0	.857	.866	.0	.01784	83.02	5855.74	221.08	11214.32
84.000	16000.0	99000.0	16000.0	.982	.992	.0	.02048	84.02	5901.80	220.96	11214.32
85.000	16000.0	99000.0	16000.0	1.143	1.158	.0	.02396	85.02	5969.11	220.79	11214.32
86.000	16000.0	99000.0	16000.0	1.375	1.385	.0	.02872	86.03	6071.77	220.55	11214.32
87.000	16000.0	99000.0	16000.0	1.702	1.711	.0	.03554	87.04	6236.67	220.22	11214.32
88.000	16000.0	99000.0	16000.0	2.203	2.207	.0	.04592	88.05	6518.53	219.73	11214.32
89.200	16000.0	99000.0	16000.0	3.270	3.249	.0	.06768	89.27	7190.68	218.87	11214.32
89.400	16000.0	99000.0	16000.0	3.534	3.505	.0	.07300	89.47	7366.71	218.69	11214.32
89.600	16000.0	99000.0	16000.0	3.836	3.795	.0	.07905	89.68	7570.18	218.51	11214.32
89.800	16000.0	99000.0	16000.0	4.184	4.126	.0	.08594	89.89	7805.23	218.32	11214.32
90.000	16000.0	99000.0	16000.0	4.528	4.507	8.6	.09384	90.09	8073.69	218.13	11154.89
90.200	16000.0	99000.0	15959.0	4.997	4.946	48.7	.10297	90.30	8407.27	217.94	11300.39
90.400	16000.0	99000.0	15837.7	5.547	5.456	94.2	.11357	90.51	8747.88	217.74	11603.19
90.600	16000.0	99000.0	15634.7	6.200	6.053	147.1	.12596	90.73	9175.94	217.56	12084.92
90.800	16000.0	99000.0	15349.9	6.984	6.756	210.0	.14055	90.94	9706.72	217.38	12772.97
91.000	16000.0	99000.0	14982.9	7.934	7.590	286.3	.15787	91.16	10449.11	217.21	13705.86
91.200	16000.0	99000.0	14532.8	9.100	8.588	380.6	.17861	91.38	11124.49	217.05	14943.40
91.400	16000.0	99000.0	13998.7	10.555	9.793	499.0	.20368	91.60	12240.57	216.90	16573.81
91.600	16000.0	99000.0	13379.1	12.168	11.263	649.8	.23421	91.83	13369.46	216.77	18721.10
91.800	16000.0	99000.0	12685.1	13.836	12.877	719.9	.25403	92.04	14827.24	218.38	21080.84
92.000	16000.0	99000.0	11898.1	16.288	14.850	837.3	.25403	92.25	16547.12	220.00	24135.13
92.200	16000.0	99000.0	11026.0	19.476	17.328	1220.6	.32435	92.52	18596.22	223.43	29001.07
92.400	16000.0	99000.0	10068.0	23.348	20.162	1502.0	.36534	92.77	21231.74	227.46	34526.57
92.600	16000.0	99000.0	9022.2	28.250	23.553	1840.2	.41192	93.01	24350.81	232.38	41694.22
92.800	16000.0	99000.0	7888.5	32.679	27.358	1911.2	.41113	93.21	28287.08	237.80	48894.63
93.000	16000.0	99000.0	6661.7	41.291	32.342	2512.6	.49181	93.49	33125.64	244.76	61676.45
93.200	16000.0	99000.0	5318.5	52.918	38.713	3373.6	.60280	93.80	39078.72	251.34	80684.50
93.400	16000.0	99000.0	3878.5	65.395	45.892	3742.0	.64015	94.04	46509.54	258.26	99730.48

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	17000.0	99000.0	17000.0	5.581	5.589	0.0	0.1206	81.01	4950.73	222.16	9573.91
82.000	17000.0	99000.0	17000.0	5.648	5.656	0.0	0.1348	82.01	4971.27	222.09	9573.91
83.000	17000.0	99000.0	17000.0	5.731	5.740	0.0	0.1524	83.02	4999.33	221.99	9573.91
84.000	17000.0	99000.0	17000.0	5.838	5.847	0.0	0.1749	84.02	5038.86	221.86	9573.91
85.000	17000.0	99000.0	17000.0	5.979	5.989	0.0	0.2047	85.02	5096.58	221.68	9573.91
86.000	17000.0	99000.0	17000.0	6.173	6.183	0.0	0.2453	86.02	5184.57	221.42	9573.91
87.000	17000.0	99000.0	17000.0	6.451	6.461	0.0	0.3036	87.03	5325.76	221.05	9573.91
88.000	17000.0	99000.0	17000.0	6.878	6.883	0.0	0.3922	88.04	5566.81	220.51	9573.91
89.200	17000.0	99000.0	17000.0	7.281	7.270	0.0	0.5779	89.26	6140.62	219.52	9573.91
89.400	17000.0	99000.0	17000.0	7.305	7.288	0.0	0.6233	89.46	6290.71	219.32	9573.91
89.600	17000.0	99000.0	17000.0	7.360	7.324	0.0	0.6748	89.67	6464.11	219.10	9573.91
89.800	17000.0	99000.0	17000.0	7.553	7.516	0.0	0.7334	89.87	6664.32	218.87	9573.91
90.000	17000.0	99000.0	17000.0	7.835	7.839	6.2	0.8006	90.08	6892.84	218.63	9511.70
90.200	17000.0	99000.0	16959.7	8.230	8.212	40.2	0.8780	90.29	7176.71	218.40	9626.18
90.400	17000.0	99000.0	16838.7	8.689	8.645	78.7	0.9678	90.50	7466.51	218.16	9872.01
90.600	17000.0	99000.0	16636.9	9.234	9.151	123.4	1.0727	90.71	7830.80	217.92	10266.53
90.800	17000.0	99000.0	16354.0	9.886	9.746	176.3	1.1961	90.92	8282.33	217.70	10831.12
91.000	17000.0	99000.0	15989.5	10.670	10.451	240.5	1.3423	91.13	8912.74	217.49	11593.14
91.200	17000.0	99000.0	15542.8	11.629	11.293	319.4	1.5171	91.35	9467.38	217.29	12603.11
91.400	17000.0	99000.0	15013.0	12.819	12.307	418.3	1.7277	91.57	10291.78	217.11	13928.30
91.600	17000.0	99000.0	14399.0	14.317	13.637	543.8	1.9841	91.80	11389.75	216.94	15664.94
91.800	17000.0	99000.0	13699.1	16.242	15.058	705.6	2.2993	92.03	12673.72	216.79	17961.34
92.000	17000.0	99000.0	12915.4	18.736	17.514	791.1	2.3935	92.24	14185.59	216.96	20557.19
92.200	17000.0	99000.0	12248.0	21.772	19.972	1104.2	2.9579	92.50	15984.73	219.31	24571.66
92.400	17000.0	99000.0	11098.9	25.289	22.574	1332.5	3.2767	92.73	18292.82	223.11	29160.94
92.600	17000.0	99000.0	10056.9	29.401	26.044	1655.4	3.7396	92.97	21060.80	227.28	35323.56
92.800	17000.0	99000.0	8929.7	34.201	28.044	1803.0	3.8685	93.19	24564.10	232.52	42004.26
93.000	17000.0	99000.0	7716.3	39.775	28.310	2129.0	4.2636	93.43	28795.49	239.14	51399.23
93.200	17000.0	99000.0	6386.0	45.223	33.989	2987.6	5.3961	93.74	34092.87	245.74	67610.37
93.400	17000.0	99000.0	4953.8	56.727	40.651	3538.5	6.0416	94.00	40782.06	252.40	85882.20

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	18000.0	99000.0	18000.0	.496	.503	.0	.01031	81.01	4226.39	223.25	8173.45
82.000	18000.0	99000.0	18000.0	.553	.560	.0	.01151	82.01	4244.03	223.17	8173.45
83.000	18000.0	99000.0	18000.0	.624	.632	.0	.01302	83.01	4268.12	223.07	8173.45
84.000	18000.0	99000.0	18000.0	.715	.723	.0	.01495	84.01	4302.04	222.93	8173.45
85.000	18000.0	99000.0	18000.0	.836	.844	.0	.01748	85.02	4351.55	222.73	8173.45
86.000	18000.0	99000.0	18000.0	1.001	1.010	.0	.02096	86.02	4426.95	222.46	8173.45
87.000	18000.0	99000.0	18000.0	1.238	1.247	.0	.02594	87.03	4547.84	222.07	8173.45
88.000	18000.0	99000.0	18000.0	1.600	1.607	.0	.03352	88.03	4753.99	221.48	8173.45
89.200	18000.0	99000.0	18000.0	2.367	2.362	.0	.04942	89.25	5243.96	220.38	8173.45
89.400	18000.0	99000.0	18000.0	2.557	2.547	.0	.05331	89.45	5371.98	220.13	8173.45
89.600	18000.0	99000.0	18000.0	2.772	2.756	.0	.05771	89.66	5519.84	219.87	8173.45
89.800	18000.0	99000.0	18000.0	3.020	2.996	.0	.06271	89.86	5690.47	219.60	8173.45
90.000	18000.0	99000.0	18000.0	3.251	3.271	4.6	.06843	90.07	5885.15	219.30	8111.00
90.200	18000.0	99000.0	17959.9	3.583	3.588	33.5	.07500	90.28	6126.87	219.00	8201.83
90.400	18000.0	99000.0	17839.6	3.970	3.955	66.1	.08261	90.48	6373.60	218.70	8402.68
90.600	18000.0	99000.0	17638.8	4.426	4.385	103.9	.09148	90.69	6683.79	218.40	8727.62
90.800	18000.0	99000.0	17357.5	4.968	4.889	148.6	.10191	90.90	7068.09	218.11	9191.55
91.000	18000.0	99000.0	16995.1	5.621	5.486	202.6	.11427	91.11	7603.83	217.84	9821.42
91.200	18000.0	99000.0	16551.2	6.415	6.198	268.9	.12901	91.33	8092.97	217.59	10651.29
91.400	18000.0	99000.0	16025.0	7.393	7.054	351.7	.14677	91.55	8776.44	217.36	11735.21
91.600	18000.0	99000.0	15415.6	8.616	8.093	456.6	.16833	91.77	9706.66	217.15	13146.15
91.800	18000.0	99000.0	14721.6	10.171	9.367	591.2	.19478	91.99	10792.74	216.97	14995.12
92.000	18000.0	99000.0	13941.3	12.196	10.945	766.7	.22757	92.23	12098.10	216.80	17453.91
92.200	18000.0	99000.0	13172.1	14.656	12.924	998.6	.26872	92.47	13677.09	216.66	20718.38
92.400	18000.0	99000.0	12126.1	17.152	15.169	1205.0	.29813	92.70	15713.01	216.55	24652.98
92.600	18000.0	99000.0	11093.2	20.712	17.850	1467.4	.33468	92.93	18137.54	222.99	29749.16
92.800	18000.0	99000.0	9968.3	25.933	21.040	1668.2	.35848	93.16	21256.52	227.36	35819.97
93.000	18000.0	99000.0	8764.1	29.440	24.731	1815.6	.37142	93.37	24718.88	233.68	43032.87
93.200	18000.0	99000.0	7450.1	33.275	29.771	2617.9	.40020	93.68	29656.13	240.23	56615.88
93.400	18000.0	99000.0	6227.6	49.918	35.993	3458.5	.58404	93.98	35374.75	246.88	74853.23
93.600	18000.0	99000.0	4521.3	63.493	43.179	4073.6	.64920	94.25	42589.51	255.11	96188.96

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SC M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	PI(EFF) (10)	TIEFF (11)	PITAN) (12)
81.000	19000.0	99000.0	19000.0	.424	.430	.0	.00876	81.01	3608.28	224.52	6977.85
82.000	19000.0	99000.0	19000.0	.472	.479	.0	.00979	82.01	3623.42	224.44	6977.85
83.000	19000.0	99000.0	19000.0	.533	.540	.0	.01107	83.01	3644.11	224.34	6977.85
84.000	19000.0	99000.0	19000.0	.610	.618	.0	.01271	84.01	3673.21	224.19	6977.85
85.000	19000.0	99000.0	19000.0	.713	.721	.0	.01486	85.01	3715.66	223.99	6977.85
86.000	19000.0	99000.0	19000.0	.854	.862	.0	.01781	86.02	3780.27	223.71	6977.85
87.000	19000.0	99000.0	19000.0	1.056	1.064	.0	.02204	87.02	3883.74	223.29	6977.85
88.000	19000.0	99000.0	19000.0	1.364	1.371	.0	.02846	88.03	4059.96	222.68	6977.85
89.200	19000.0	99000.0	19000.0	2.015	2.013	.0	.04192	89.24	4477.91	221.54	6977.85
89.400	19000.0	99000.0	19000.0	2.176	2.169	.0	.04520	89.45	4586.96	221.29	6977.85
89.600	19000.0	99000.0	19000.0	2.359	2.348	.0	.04892	89.65	4712.82	221.02	6977.85
89.800	19000.0	99000.0	19000.0	2.568	2.551	.0	.05314	89.85	4857.99	220.73	6977.85
90.000	19000.0	99000.0	19000.0	2.740	2.783	3.3	.05796	90.06	5023.50	220.43	6917.56
90.200	19000.0	99000.0	19000.0	3.039	3.053	28.1	.06477	90.26	5230.04	220.02	6989.69
90.400	19000.0	99000.0	19000.0	3.367	3.368	57.0	.07257	90.47	5441.31	219.55	7156.41
90.600	19000.0	99000.0	19000.0	3.749	3.734	88.6	.07935	90.68	5705.81	219.07	7425.25
90.800	19000.0	99000.0	19000.0	4.203	4.162	126.0	.08764	90.89	6033.12	218.68	7809.41
91.000	19000.0	99000.0	19000.0	4.747	4.669	171.5	.09790	91.10	6488.90	218.31	8331.16
91.200	19000.0	99000.0	19000.0	5.407	5.272	227.3	.11023	91.31	6905.35	217.99	9016.88
91.400	19000.0	99000.0	19000.0	6.214	5.996	296.8	.12515	91.53	7486.51	217.69	9907.23
91.600	19000.0	99000.0	19000.0	7.219	6.874	384.7	.14328	91.74	8275.58	217.43	11062.37
91.800	19000.0	99000.0	19000.0	8.487	7.946	497.2	.16550	91.97	9195.50	217.19	12564.90
92.000	19000.0	99000.0	19000.0	10.121	9.271	643.1	.19299	92.19	10300.85	216.99	14543.64
92.200	19000.0	99000.0	19000.0	12.273	10.927	835.2	.22738	92.43	11638.41	216.81	17191.41
92.400	19000.0	99000.0	19000.0	14.901	13.024	1091.9	.27095	92.67	13436.61	216.66	20755.52
92.600	19000.0	99000.0	19000.0	17.744	15.445	1326.1	.30403	92.90	15574.82	216.07	25096.57
92.800	19000.0	99000.0	19000.0	21.754	18.357	1631.8	.34598	93.15	18136.17	223.09	30823.31
93.000	19000.0	99000.0	9008.6	25.539	21.595	1612.1	.33311	93.33	21387.33	228.46	36338.32
93.200	19000.0	99000.0	8505.5	33.022	26.057	2345.8	.43383	93.63	25483.51	234.82	47722.54
93.400	19000.0	99000.0	7095.0	42.594	31.311	3055.6	.52192	93.92	30794.24	241.41	62493.45
93.600	19000.0	99000.0	5607.3	53.411	37.664	3559.0	.57550	94.18	37187.23	249.42	79678.18

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MID-LATITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SC M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M(H) HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
61.000	20000.0	99500.0	20000.0	.362	.367	.0	-.00746	81.01	3082.85	225.84	5962.02
62.000	20000.0	99500.0	20000.0	.423	.409	.0	-.00833	82.01	3095.86	225.76	5962.02
63.000	20000.0	99500.0	20000.0	.455	.462	.0	-.00942	83.01	3113.63	225.65	5962.02
64.000	20000.0	99500.0	20000.0	.521	.528	.0	-.01081	84.01	3138.62	225.50	5962.02
65.000	20000.0	99500.0	20000.0	.609	.616	.0	-.01264	85.01	3175.05	225.29	5962.02
66.000	20000.0	99500.0	20000.0	.729	.737	.0	-.01515	86.02	3230.44	224.99	5962.02
67.000	20000.0	99500.0	20000.0	.901	.909	.0	-.01874	87.02	3319.06	224.56	5962.02
68.000	20000.0	99500.0	20000.0	1.163	1.171	.0	-.02419	88.02	3469.80	223.92	5962.02
69.200	20000.0	99500.0	20000.0	1.715	1.717	.0	-.03559	89.24	3826.62	222.73	5962.02
69.400	20000.0	99500.0	20000.0	1.851	1.850	.0	-.03837	89.44	3919.58	222.47	5962.02
69.600	20000.0	99500.0	20000.0	2.005	2.001	.0	-.04151	89.64	4026.83	222.19	5962.02
69.800	20000.0	99500.0	20000.0	2.182	2.173	.0	-.04508	89.85	4150.45	221.89	5962.02
90.000	20000.0	99500.0	20000.0	2.322	2.371	2.4	-.04915	90.05	4291.33	221.58	5904.13
90.200	20000.0	99500.0	19960.1	2.558	2.600	23.3	-.05489	90.25	4466.85	221.16	5960.71
90.400	20000.0	99500.0	19840.5	2.848	2.866	47.6	-.06146	90.46	4646.46	220.68	6098.29
90.600	20000.0	99500.0	19641.2	3.169	3.175	74.2	-.06716	90.67	4871.39	220.19	6320.60
90.800	20000.0	99500.0	19362.3	3.547	3.538	105.7	-.07414	90.87	5149.44	219.78	6638.67
91.000	20000.0	99500.0	19003.3	4.017	3.965	143.8	-.08273	91.08	5452.66	219.41	7070.06
91.200	20000.0	99500.0	18562.9	4.571	4.483	194.1	-.09488	91.29	5892.51	218.68	7644.13
91.400	20000.0	99500.0	18042.3	5.241	5.098	251.7	-.10700	91.51	6387.33	218.22	8379.86
91.600	20000.0	99500.0	17440.0	6.071	5.840	325.2	-.12216	91.72	7057.46	217.85	9331.33
91.800	20000.0	99500.0	16755.4	7.112	6.745	419.4	-.14082	91.94	7737.18	217.53	10561.58
92.000	20000.0	99500.0	15986.5	8.442	7.862	541.3	-.16391	92.16	8774.61	217.26	12168.86
92.200	20000.0	99500.0	15132.0	10.174	9.253	701.0	-.19273	92.39	9908.91	217.03	14296.46
92.400	20000.0	99500.0	14189.6	12.489	11.007	913.5	-.22913	92.63	11426.75	216.83	17172.61
92.600	20000.0	99500.0	13156.6	15.126	13.249	1200.3	-.27572	92.88	13313.35	216.66	21108.88
92.800	20000.0	99500.0	12043.5	18.590	15.875	1472.2	-.31353	93.11	15573.25	219.16	25942.41
93.000	20000.0	99500.0	10849.9	22.096	18.821	1521.1	-.31237	93.31	18452.29	223.86	31025.94
93.200	20000.0	99500.0	9567.5	27.923	22.682	2049.7	-.38352	93.58	22038.39	229.88	36911.13
93.400	20000.0	99500.0	8163.1	36.175	27.574	2739.0	-.47144	93.87	26743.48	235.93	52486.79
93.600	20000.0	99500.0	6686.7	44.634	33.124	3071.9	-.50479	94.10	32373.32	243.84	65900.61
93.800	20000.0	99500.0	5075.9	62.606	40.899	4327.2	-.64949	94.45	39642.86	251.50	92881.35

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	21000.0	99000.0	21000.0	.309	.314	.0	.00635	81.01	2635.87	227.21	5097.75
82.000	21000.0	99000.0	21000.0	.345	.350	.0	.00710	82.01	2647.06	227.13	5097.75
83.000	21000.0	99000.0	21000.0	.389	.395	.0	.00802	83.01	2662.34	227.01	5097.75
84.000	21000.0	99000.0	21000.0	.445	.452	.0	.00921	84.01	2683.81	226.85	5097.75
85.000	21000.0	99000.0	21000.0	.520	.527	.0	.01077	85.01	2715.08	226.63	5097.75
86.000	21000.0	99000.0	21000.0	.622	.630	.0	.01290	86.01	2762.61	226.32	5097.75
87.000	21000.0	99000.0	21000.0	.769	.777	.0	.01595	87.02	2838.57	225.87	5097.75
88.000	21000.0	99000.0	21000.0	.993	1.000	.0	.02058	88.02	2967.59	225.21	5097.75
89.200	21000.0	99000.0	21000.0	1.461	1.465	.0	.03026	89.23	3272.44	223.97	5097.75
89.400	21000.0	99000.0	21000.0	1.576	1.579	.0	.03261	89.43	3351.78	223.70	5097.75
89.600	21000.0	99000.0	21000.0	1.707	1.707	.0	.03527	89.64	3443.25	223.41	5097.75
89.800	21000.0	99000.0	21000.0	1.856	1.854	.0	.03829	89.84	3548.63	223.10	5097.75
90.000	21000.0	99000.0	21000.0	1.970	2.022	1.7	.04173	90.04	3668.67	222.77	5042.82
90.200	21000.0	99000.0	20960.0	2.169	2.216	19.4	.04658	90.25	3818.01	222.33	5088.23
90.400	21000.0	99000.0	20841.0	2.414	2.441	39.9	.05212	90.45	3970.87	221.84	5201.71
90.600	21000.0	99000.0	20642.5	2.683	2.704	62.4	.05695	90.66	4162.35	221.33	5386.42
90.800	21000.0	99000.0	20384.5	3.000	3.010	88.9	.06281	90.86	4398.80	220.91	5651.03
91.000	21000.0	99000.0	20006.9	3.392	3.372	120.9	.07003	91.07	4650.59	220.52	6009.55
91.200	21000.0	99000.0	19568.4	3.853	3.809	163.1	.08024	91.28	5029.76	219.78	6485.12
91.400	21000.0	99000.0	19050.0	4.423	4.327	211.2	.09040	91.49	5449.40	219.31	7093.32
91.600	21000.0	99000.0	18449.6	5.117	4.963	277.1	.10471	91.70	6020.05	218.52	7886.94
91.800	21000.0	99000.0	17768.2	5.976	5.730	355.1	.12039	91.92	6598.89	218.04	8899.50
92.000	21000.0	99000.0	16155.1	7.065	6.673	457.0	.13944	92.14	7383.66	217.65	10212.74
92.200	21000.0	99000.0	15200.1	8.472	7.845	590.3	.16363	92.36	8440.51	217.33	11938.43
92.400	21000.0	99000.0	14196.3	10.332	9.317	767.0	.19413	92.59	9723.50	217.07	14246.37
92.600	21000.0	99000.0	13079.9	12.856	11.191	1004.2	.23302	92.83	11317.14	216.85	17405.94
92.800	21000.0	99000.0	11889.2	15.802	13.613	1328.2	.28334	93.08	13311.72	216.67	21762.91
93.000	21000.0	99000.0	10609.0	18.906	16.296	1371.9	.28271	93.28	15854.80	219.74	26146.27
93.200	21000.0	99000.0	9225.2	23.818	19.708	1834.4	.34519	93.55	19004.07	225.24	33547.59
93.400	21000.0	99000.0	7758.8	30.546	23.999	2415.9	.41962	93.82	23130.12	231.01	43824.16
93.600	21000.0	99000.0	6166.0	36.776	28.791	2431.5	.41419	94.01	27797.34	238.18	53140.73
93.800	21000.0	99000.0		51.804	35.795	3822.2	.57981	94.38	34548.56	245.98	76903.73

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (IAN) (12)
81.000	22000.0	99000.0	22000.0	.265	.269	.0	.00541	81.01	2255.35	228.64	4361.89
82.000	22000.0	99000.0	22000.0	.295	.300	.0	.00605	82.01	2264.99	228.55	4361.89
83.000	22000.0	99000.0	22000.0	.333	.338	.0	.00684	83.01	2278.12	228.43	4361.89
84.000	22000.0	99000.0	22000.0	.381	.387	.0	.00785	84.01	2296.58	228.27	4361.89
85.000	22000.0	99000.0	22000.0	.445	.451	.0	.00917	85.01	2323.46	228.04	4361.89
86.000	22000.0	99000.0	22000.0	.532	.539	.0	.01099	86.01	2364.26	227.72	4361.89
87.000	22000.0	99000.0	22000.0	.657	.665	.0	.01359	87.01	2429.39	227.25	4361.89
88.000	22000.0	99000.0	22000.0	.848	.856	.0	.01753	88.02	2539.89	226.56	4361.89
89.200	22000.0	99000.0	22000.0	1.246	1.252	.0	.02576	89.23	2800.50	225.28	4361.89
89.400	22000.0	99000.0	22000.0	1.344	1.348	.0	.02776	89.43	2868.24	225.00	4361.89
89.600	22000.0	99000.0	22000.0	1.455	1.458	.0	.03003	89.63	2946.33	224.69	4361.89
89.800	22000.0	99000.0	22000.0	1.581	1.583	.0	.03259	89.83	3036.26	224.37	4361.89
90.000	22000.0	99000.0	22000.0	1.674	1.725	1.2	.03551	90.04	3138.65	224.02	4310.19
90.200	22000.0	99000.0	21960.4	1.842	1.890	16.3	.03960	90.24	3265.87	223.56	4346.92
90.400	22000.0	99000.0	21841.5	2.048	2.082	33.6	.04427	90.44	3396.13	223.04	4441.01
90.600	22000.0	99000.0	21643.5	2.275	2.304	52.6	.04835	90.65	3559.29	222.51	4595.13
90.800	22000.0	99000.0	21366.4	2.541	2.565	75.0	.05328	90.85	3760.59	222.07	4816.16
91.000	22000.0	99000.0	21009.8	2.870	2.871	101.9	.05936	91.06	3979.97	221.66	5115.39
91.200	22000.0	99000.0	20572.5	3.254	3.240	137.4	.06796	91.27	4296.95	220.90	5509.88
91.400	22000.0	99000.0	20256.4	3.732	3.678	177.8	.07648	91.48	4653.27	220.41	6016.52
91.600	22000.0	99000.0	19458.5	4.303	4.213	232.9	.08850	91.69	5136.46	219.62	6671.11
91.800	22000.0	99000.0	18779.4	5.039	4.867	309.1	.10456	91.90	5629.53	218.89	7520.77
92.000	22000.0	99000.0	18018.6	5.932	5.667	387.6	.11895	92.12	6296.81	218.23	8596.09
92.200	22000.0	99000.0	17174.5	7.084	6.656	498.7	.13917	92.34	7192.88	217.77	10006.49
92.400	22000.0	99000.0	16245.6	8.590	7.896	646.1	.16476	92.56	8278.74	217.40	11872.89
92.600	22000.0	99000.0	15229.6	10.609	9.469	843.2	.19732	92.80	9626.70	217.11	14397.63
92.800	22000.0	99000.0	14123.5	13.397	11.491	1110.9	.23930	93.04	11313.93	216.87	17907.21
93.000	22000.0	99000.0	12926.5	16.275	14.036	1307.4	.28649	93.27	13572.47	216.90	22200.83
93.200	22000.0	99000.0	11656.1	20.389	17.016	1592.4	.30272	93.50	16320.34	221.30	27935.40
93.400	22000.0	99000.0	10279.7	26.299	20.860	2165.9	.37811	93.78	19752.46	226.23	36754.85
93.600	22000.0	99000.0	8818.9	31.930	25.254	2311.5	.39074	93.99	24133.28	232.76	45593.49
93.800	22000.0	99000.0	7248.1	43.415	31.272	3366.3	.51582	94.32	30022.36	240.57	63777.79
94.000	22000.0	99000.0	5580.5	56.823	38.405	4061.1	.58871	94.59	36957.84	249.23	84833.04

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SC M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF) (10)	TIEFF) (11)	PITAN) (12)
81.000	23000.0	99000.0	23000.0	.227	.231	.0	.00460	81.00	1931.35	230.13	3734.89
82.000	23000.0	99000.0	23000.0	.252	.257	.0	.00513	82.01	1939.65	230.04	3734.89
83.000	23000.0	99000.0	23000.0	.285	.290	.0	.00580	83.01	1950.96	229.92	3734.89
84.000	23000.0	99000.0	23000.0	.326	.332	.0	.00666	84.01	1966.84	229.75	3734.89
85.000	23000.0	99000.0	23000.0	.381	.387	.0	.00779	85.01	1989.95	229.51	3734.89
86.000	23000.0	99000.0	23000.0	.455	.462	.0	.00932	86.01	2024.99	229.17	3734.89
87.000	23000.0	99000.0	23000.0	.562	.570	.0	.01152	87.01	2080.88	228.69	3734.89
88.000	23000.0	99000.0	23000.0	.725	.732	.0	.01484	88.01	2175.54	227.98	3734.89
89.200	23000.0	99000.0	23000.0	1.064	1.070	.0	.02175	89.22	2398.24	226.71	3734.89
89.400	23000.0	99000.0	23000.0	1.147	1.152	.0	.02342	89.42	2456.03	226.45	3734.89
89.600	23000.0	99000.0	23000.0	1.241	1.245	.0	.02532	89.63	2522.60	226.16	3734.89
89.800	23000.0	99000.0	23000.0	1.348	1.351	.0	.02746	89.83	2599.22	225.87	3734.89
90.000	23000.0	99000.0	23000.0	1.474	1.472	.9	.02991	90.03	2686.41	225.56	3687.07
90.200	23000.0	99000.0	22960.4	1.557	1.612	13.7	.03399	90.23	2794.94	225.05	3716.94
90.400	23000.0	99000.0	22841.7	1.741	1.776	28.9	.03862	90.44	2906.43	224.43	3795.30
90.600	23000.0	99000.0	22644.0	1.932	1.966	44.8	.04172	90.64	3045.87	223.78	3924.36
90.800	23000.0	99000.0	22367.6	2.157	2.187	63.5	.04561	90.85	3217.51	223.28	4109.54
91.000	23000.0	99000.0	22111.9	2.423	2.447	86.2	.05063	91.05	3404.44	222.84	4359.42
91.200	23000.0	99000.0	21576.2	2.754	2.760	116.1	.05783	91.26	3674.06	222.05	4689.85
91.400	23000.0	99000.0	21061.2	3.152	3.130	150.0	.06496	91.46	3976.97	221.54	5112.70
91.600	23000.0	99000.0	20465.5	3.629	3.583	196.2	.07504	91.68	4386.75	220.73	5656.69
91.800	23000.0	99000.0	19789.0	4.237	4.133	259.8	.08844	91.89	4805.24	220.00	6358.24
92.000	23000.0	99000.0	19031.4	4.987	4.806	325.5	.10052	92.10	5370.63	219.31	7243.89
92.200	23000.0	99000.0	18190.6	5.942	5.651	423.6	.11886	92.32	6132.31	218.39	8411.32
92.400	23000.0	99000.0	17266.7	7.171	6.699	546.1	.14018	92.54	6968.50	217.86	9933.76
92.600	23000.0	99000.0	16257.2	8.803	8.023	719.4	.16748	92.77	8095.60	217.45	11972.42
92.800	23000.0	99000.0	15159.5	11.024	9.719	932.7	.20260	93.00	9623.19	217.13	14765.58
93.000	23000.0	99000.0	13975.2	13.941	11.924	1237.9	.24836	93.25	11551.77	216.87	18712.28
93.200	23000.0	99000.0	12597.0	17.314	14.640	1433.8	.27304	93.47	13970.39	218.16	23414.31
93.400	23000.0	99000.0	11331.8	22.182	18.024	1911.2	.33583	93.74	16978.86	222.22	30626.60
93.600	23000.0	99000.0	9475.6	27.237	22.016	2088.2	.35420	93.95	20864.42	227.62	38436.99
93.800	23000.0	99000.0	8319.6	37.079	27.311	3011.6	.46441	94.26	25807.66	235.19	53272.19
94.000	23000.0	99000.0	6669.7	47.591	33.550	3511.4	.51618	94.52	32156.76	243.68	69692.86
94.200	23000.0	99000.0	4490.7	63.409	41.697	4343.9	.60437	94.80	40242.64	252.05	95086.32

UNREFRACTED RAY STRIKES DISC



## REFRACTION: AIRMASS TABLES

MIDLATITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ CM  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	24000.0	99000.0	24000.0	.194	.198	.0	.00393	81.00	1656.20	231.53	3202.77
82.000	24000.0	99000.0	24000.0	.216	.221	.0	.00439	82.00	1663.35	231.43	3202.77
83.000	24000.0	99000.0	24000.0	.244	.249	.0	.00496	83.00	1673.10	231.30	3202.77
84.000	24000.0	99000.0	24000.0	.279	.285	.0	.00569	84.01	1686.79	231.12	3202.77
85.000	24000.0	99000.0	24000.0	.326	.332	.0	.00665	85.01	1706.69	230.87	3202.77
86.000	24000.0	99000.0	24000.0	.390	.396	.0	.00796	86.01	1736.85	230.51	3202.77
87.000	24000.0	99000.0	24000.0	.481	.488	.0	.00983	87.01	1784.89	229.99	3202.77
88.000	24000.0	99000.0	24000.0	.623	.628	.0	.01266	88.01	1866.14	229.23	3202.77
89.200	24000.0	99000.0	24000.0	.908	.917	.0	.01853	89.22	2056.92	227.87	3202.77
89.400	24000.0	99000.0	24000.0	.979	.987	.0	.01996	89.42	2106.37	227.59	3202.77
89.600	24000.0	99000.0	24000.0	1.059	1.066	.0	.02157	89.62	2163.31	227.30	3202.77
89.800	24000.0	99000.0	24000.0	1.149	1.157	.0	.02339	89.82	2228.81	226.99	3202.77
90.000	24000.0	99000.0	24000.0	1.210	1.260	.6	.02546	90.03	2303.33	226.67	3157.94
90.200	24000.0	99000.0	23960.0	1.330	1.379	11.3	.02838	90.23	2355.68	226.26	3182.29
90.400	24000.0	99000.0	23842.3	1.477	1.517	23.7	.03171	90.43	2490.32	225.78	3247.49
90.600	24000.0	99000.0	23645.2	1.638	1.677	37.2	.03461	90.63	2608.80	225.29	3355.43
90.800	24000.0	99000.0	23369.3	1.827	1.864	53.1	.03812	90.84	2754.66	224.89	3510.50
91.000	24000.0	99000.0	23014.4	2.050	2.083	72.2	.04242	91.04	2913.54	224.52	3719.51
91.200	24000.0	99000.0	22579.4	2.338	2.351	99.0	.04942	91.25	3143.57	223.41	3997.42
91.400	24000.0	99000.0	22265.7	2.661	2.666	127.1	.05520	91.46	3401.59	222.81	4350.62
91.600	24000.0	99000.0	21471.7	3.069	3.049	165.8	.06364	91.66	3749.65	221.94	4805.32
91.800	24000.0	99000.0	20797.4	3.574	3.514	218.9	.07483	91.87	4105.33	221.18	5387.71
92.000	24000.0	99000.0	20442.5	4.195	4.082	274.0	.08500	92.09	4585.02	220.45	6121.70
92.200	24000.0	99000.0	19205.2	4.993	4.793	355.9	.10036	92.30	5229.02	219.51	7081.43
92.400	24000.0	99000.0	18284.8	6.011	5.685	464.1	.11965	92.52	5941.42	218.55	8340.14
92.600	24000.0	99000.0	17280.8	7.340	6.824	600.4	.14235	92.74	6898.32	217.94	9999.31
92.800	24000.0	99000.0	16190.2	9.128	8.231	785.6	.17178	92.97	8190.12	217.49	12246.94
93.000	24000.0	99000.0	15110.3	11.607	10.078	1038.8	.21004	93.21	9701.03	217.14	15376.73
93.200	24000.0	99000.0	13736.7	14.929	12.506	1390.3	.26045	93.46	11911.33	216.87	19863.39
93.400	24000.0	99000.0	12377.7	18.046	15.526	1724.9	.30346	93.70	14549.42	216.75	25636.81
93.600	24000.0	99000.0	10928.6	23.539	19.141	1978.0	.33261	93.93	17961.35	223.22	32743.78
93.800	24000.0	99000.0	9388.3	31.119	23.731	2645.7	.41135	94.21	22305.90	230.32	44208.35
94.000	24000.0	99000.0	7751.1	38.684	29.097	2753.8	.41928	94.42	27582.14	238.09	55436.03
94.200	24000.0	99000.0	5961.9	55.194	36.798	4193.0	.57801	94.78	35171.55	246.39	82182.23

UNREFRACTED RAY STRIKES DISC

## REFRACTION: AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/5Q M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	25000.0	99000.0	25000.0	.167	.170	.0	.00336	81.00	1421.30	232.98	2748.11
82.000	25000.0	99000.0	25000.0	.186	.189	.0	.00375	82.00	1427.48	232.88	2748.11
83.000	25000.0	99000.0	25000.0	.209	.214	.0	.00424	83.00	1435.89	232.74	2748.11
84.000	25000.0	99000.0	25000.0	.240	.244	.0	.00486	84.00	1447.70	232.55	2748.11
85.000	25000.0	99000.0	25000.0	.280	.285	.0	.00568	85.01	1464.86	232.28	2748.11
86.000	25000.0	99000.0	25000.0	.334	.340	.0	.00680	86.01	1490.84	231.90	2748.11
87.000	25000.0	99000.0	25000.0	.413	.419	.0	.00840	87.01	1532.19	231.35	2748.11
88.000	25000.0	99000.0	25000.0	.531	.539	.0	.01081	88.01	1602.01	230.52	2748.11
89.200	25000.0	99000.0	25000.0	.778	.786	.0	.01582	89.22	1765.60	229.04	2748.11
89.400	25000.0	99000.0	25000.0	.838	.846	.0	.01700	89.42	1807.94	228.73	2748.11
89.600	25000.0	99000.0	25000.0	.906	.914	.0	.01837	89.62	1856.67	228.42	2748.11
89.800	25000.0	99000.0	25000.0	.983	.991	.0	.01991	89.82	1912.70	228.10	2748.11
90.000	25000.0	99000.0	25000.0	1.032	1.080	.5	.02167	90.02	1976.43	227.77	2706.53
90.200	25000.0	99000.0	24960.6	1.134	1.181	9.6	.02415	90.22	2055.32	227.35	2726.61
90.400	25000.0	99000.0	24842.5	1.259	1.299	20.0	.02698	90.43	2136.20	226.87	2781.36
90.600	25000.0	99000.0	24645.8	1.395	1.435	31.5	.02945	90.63	2237.45	226.38	2872.38
90.800	25000.0	99000.0	24370.4	1.555	1.594	45.0	.03243	90.83	2362.02	225.98	3003.24
91.000	25000.0	99000.0	24016.1	1.744	1.781	61.2	.03608	91.04	2497.68	225.60	3179.54
91.200	25000.0	99000.0	23582.4	1.977	2.005	82.4	.04123	91.24	2692.58	224.88	3411.62
91.400	25000.0	99000.0	23169.9	2.248	2.270	106.3	.04628	91.45	2911.36	224.42	3707.33
91.600	25000.0	99000.0	22476.9	2.599	2.597	141.1	.05424	91.65	3207.68	223.25	4089.30
91.800	25000.0	99000.0	21804.4	3.020	2.991	185.1	.06346	91.86	3510.40	222.42	4574.78
92.000	25000.0	99000.0	21051.8	3.537	3.472	231.3	.07200	92.07	3917.92	221.62	5185.97
92.200	25000.0	99000.0	20217.4	4.197	4.071	299.8	.08488	92.28	4463.30	220.65	5979.64
92.400	25000.0	99000.0	19300.6	5.145	4.822	390.1	.10103	92.50	5067.29	219.66	7013.01
92.600	25000.0	99000.0	18300.6	6.141	5.773	510.4	.12147	92.72	5880.52	218.64	8380.48
92.800	25000.0	99000.0	17216.1	7.593	6.978	663.8	.14594	92.95	6974.46	217.98	10204.16
93.000	25000.0	99000.0	16143.8	9.582	8.531	874.6	.17798	93.18	8256.81	217.50	12713.94
93.200	25000.0	99000.0	14780.6	12.393	10.563	1165.8	.22009	93.42	10001.90	217.13	16274.96
93.400	25000.0	99000.0	13421.4	15.981	13.267	1575.4	.27625	93.68	12411.67	216.85	21458.74
93.600	25000.0	99000.0	11976.3	20.471	16.566	1854.3	.30981	93.91	15441.50	219.29	27699.07
93.800	25000.0	99000.0	10448.2	26.672	20.591	2367.7	.36957	94.17	19226.50	225.68	36923.36
94.000	25000.0	99000.0	8817.5	33.530	25.501	2621.0	.39570	94.40	23940.08	232.66	47493.75
94.200	25000.0	99000.0	7171.6	47.761	32.281	3918.2	.53825	94.74	30356.41	241.06	69736.07
94.400	25000.0	99000.0	5222.4	65.678	40.549	4958.3	.64203	95.04	38712.78	250.61	98261.54

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/50 M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	26000.0	99000.0	26000.0	.143	.146	.0	.00289	81.00	1220.52	234.50	2359.61
82.000	26000.0	99000.0	26000.0	.159	.163	.0	.00322	82.00	1225.86	234.39	2359.61
83.000	26000.0	99000.0	26000.0	.180	.184	.0	.00364	83.00	1233.14	234.25	2359.61
84.000	26000.0	99000.0	26000.0	.206	.210	.0	.00418	84.00	1243.34	234.05	2359.61
85.000	26000.0	99000.0	26000.0	.240	.245	.0	.00489	85.00	1258.15	233.77	2359.61
86.000	26000.0	99000.0	26000.0	.287	.292	.0	.00585	86.00	1280.56	233.36	2359.61
87.000	26000.0	99000.0	26000.0	.354	.360	.0	.00722	87.00	1316.19	232.76	2359.61
88.000	26000.0	99000.0	26000.0	.455	.462	.0	.00930	88.00	1376.28	231.85	2359.61
89.000	26000.0	99000.0	26000.0	.666	.675	.0	.01360	89.00	1516.86	230.14	2359.61
89.400	26000.0	99000.0	26000.0	.717	.726	.0	.01463	89.41	1553.21	229.78	2359.61
89.600	26000.0	99000.0	26000.0	.775	.785	.0	.01580	89.62	1595.03	229.40	2359.61
89.800	26000.0	99000.0	26000.0	.841	.851	.0	.01713	89.82	1643.10	229.01	2359.61
90.000	26000.0	99000.0	26000.0	.887	.897	.0	.01864	90.02	1697.76	228.61	2320.81
90.200	26000.0	99000.0	25960.7	.973	.927	8.0	.02038	90.22	1765.23	228.21	2337.49
90.400	26000.0	99000.0	25842.9	1.073	1.013	16.6	.02237	90.42	1834.21	227.81	2383.73
90.600	26000.0	99000.0	25646.5	1.190	1.114	26.5	.02469	90.62	1920.56	227.41	2460.68
90.800	26000.0	99000.0	25371.5	1.325	1.365	38.1	.02739	90.83	2026.92	227.03	2571.40
91.000	26000.0	99000.0	25017.7	1.485	1.524	51.9	.03056	91.03	2142.80	226.67	2720.49
91.200	26000.0	99000.0	24584.8	1.683	1.715	69.9	.03497	91.23	2309.11	225.96	2916.42
91.400	26000.0	99000.0	24073.1	1.911	1.940	90.2	.03927	91.44	2495.75	225.49	3165.91
91.600	26000.0	99000.0	23481.8	2.197	2.214	117.7	.04531	91.65	2746.53	224.72	3484.72
91.800	26000.0	99000.0	22810.6	2.558	2.547	159.9	.05466	91.85	3003.86	223.87	3893.09
92.000	26000.0	99000.0	22059.6	2.989	2.956	195.9	.06109	92.06	3350.68	222.86	4402.53
92.200	26000.0	99000.0	21227.8	3.527	3.463	253.2	.07186	92.27	3813.27	221.83	5061.50
92.400	26000.0	99000.0	20314.3	4.225	4.096	328.7	.08540	92.49	4325.99	220.81	5915.24
92.600	26000.0	99000.0	19318.2	5.148	4.896	429.0	.10251	92.70	5014.42	219.76	7036.96
92.800	26000.0	99000.0	18237.0	6.344	5.920	563.9	.12439	92.92	5941.98	218.67	8537.93
93.000	26000.0	99000.0	17072.1	7.951	7.230	738.6	.15108	93.15	7031.43	217.97	10565.43
93.200	26000.0	99000.0	15817.5	10.193	8.937	980.9	.18633	93.39	8508.95	217.48	13403.18
93.400	26000.0	99000.0	14472.0	13.437	11.196	1319.6	.23318	93.63	10538.18	217.10	17521.28
93.600	26000.0	99000.0	13023.4	17.649	14.243	1802.3	.29648	93.90	13052.01	216.82	23564.93
93.800	26000.0	99000.0	11505.2	22.372	17.763	2077.9	.32628	94.13	16323.52	221.78	30597.64
94.000	26000.0	99000.0	9880.1	28.518	22.215	2375.6	.35918	94.36	20690.15	227.54	39924.50
94.200	26000.0	99000.0	8151.2	40.118	28.171	3504.2	.48401	94.68	26335.56	235.67	57945.46
94.400	26000.0	99000.0	6322.8	54.224	35.419	4366.9	.57060	94.97	33402.82	245.12	80580.99

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MUTUALITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMIC ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	27000.0	99000.0	27000.0	.123	.126	.0	.00248	81.00	1048.14	236.29	2025.86
82.000	27000.0	99000.0	27000.0	.137	.140	.0	.00277	82.00	1052.76	236.18	2025.86
83.000	27000.0	99000.0	27000.0	.154	.158	.0	.00313	83.00	1059.05	236.03	2025.86
84.000	27000.0	99000.0	27000.0	.177	.180	.0	.00359	84.00	1067.86	235.82	2025.86
85.000	27000.0	99000.0	27000.0	.206	.210	.0	.00420	85.00	1080.65	235.53	2025.86
86.000	27000.0	99000.0	27000.0	.246	.251	.0	.00503	86.01	1099.99	235.10	2025.86
87.000	27000.0	99000.0	27000.0	.304	.309	.0	.00621	87.01	1130.70	234.46	2025.86
88.000	27000.0	99000.0	27000.0	.391	.397	.0	.00800	88.01	1182.44	233.47	2025.86
89.200	27000.0	99000.0	27000.0	.571	.579	.0	.01171	89.21	1303.30	231.54	2025.86
89.400	27000.0	99000.0	27000.0	.615	.623	.0	.01261	89.41	1334.52	231.11	2025.86
89.600	27000.0	99000.0	27000.0	.665	.673	.0	.01362	89.61	1370.42	230.66	2025.86
89.800	27000.0	99000.0	27000.0	.722	.730	.0	.01476	89.81	1411.68	230.19	2025.86
90.000	27000.0	99000.0	27000.0	.758	.795	.3	.01606	90.02	1458.58	229.70	1989.97
90.200	27000.0	99000.0	26960.0	.833	.870	6.9	.01754	90.22	1516.46	229.20	2003.93
90.400	27000.0	99000.0	26843.1	.918	.956	14.3	.01926	90.42	1575.60	228.69	2043.19
90.600	27000.0	99000.0	26646.9	1.018	1.055	22.7	.02124	90.62	1649.66	228.20	2108.65
90.800	27000.0	99000.0	26372.1	1.134	1.172	32.7	.02355	90.82	1740.87	227.72	2202.91
91.000	27000.0	99000.0	26148.7	1.270	1.308	44.5	.02627	91.03	1840.24	227.27	2329.82
91.200	27000.0	99000.0	25886.6	1.432	1.469	58.8	.02947	91.23	1981.98	226.85	2495.50
91.400	27000.0	99000.0	25675.7	1.625	1.661	76.4	.03329	91.43	2141.17	226.46	2706.62
91.600	27000.0	99000.0	24485.3	1.867	1.893	99.7	.03846	91.64	2354.88	225.72	2975.64
91.800	27000.0	99000.0	23815.7	2.161	2.174	131.1	.04511	91.85	2573.74	225.07	3315.14
92.000	27000.0	99000.0	23566.5	2.529	2.517	163.9	.05122	92.05	2867.46	224.37	3742.73
92.200	27000.0	99000.0	22236.3	2.979	2.949	214.7	.06103	92.26	3260.71	223.06	4294.94
92.400	27000.0	99000.0	21325.4	3.559	3.484	277.6	.07232	92.47	3696.53	221.97	5004.01
92.600	27000.0	99000.0	20332.7	4.308	4.159	361.5	.08667	92.69	4280.18	220.88	5928.63
92.800	27000.0	99000.0	19256.7	5.309	5.020	473.9	.10497	92.90	5003.41	219.77	7156.33
93.000	27000.0	99000.0	18095.7	6.628	6.133	626.7	.12865	93.13	5990.76	218.62	8819.13
93.200	27000.0	99000.0	16848.3	8.434	7.572	827.9	.15807	93.36	7243.27	217.92	11103.94
93.400	27000.0	99000.0	15510.4	11.003	9.467	1109.4	.19727	93.60	8849.41	217.42	14364.29
93.600	27000.0	99000.0	14077.1	14.591	12.008	1507.8	.24999	93.85	11081.68	217.05	19190.68
93.800	27000.0	99000.0	12554.5	18.947	15.277	1874.6	.29438	94.09	13974.58	218.54	25535.82
94.000	27000.0	99000.0	10937.7	24.616	19.302	2255.1	.33780	94.34	17825.29	223.17	33978.41
94.200	27000.0	99000.0	9226.5	33.882	24.465	3086.7	.42926	94.63	22753.41	230.82	47847.36
94.400	27000.0	99000.0	7413.1	45.375	30.888	3827.8	.50469	94.90	29007.55	239.73	66139.08
94.600	27000.0	99000.0	5481.6	63.437	39.252	4907.7	.61075	95.21	37355.90	249.47	94787.34

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	28000.0	99000.0	28000.0	.105	.128	.0	.00213	81.00	900.14	238.37	1739.32
82.000	28000.0	99000.0	28000.0	.117	.120	.0	.00238	82.00	904.13	238.26	1739.32
83.000	28000.0	99000.0	28000.0	.132	.135	.0	.00269	83.00	909.56	238.11	1739.32
84.000	28000.0	99000.0	28000.0	.152	.155	.0	.00309	84.00	917.18	237.90	1739.32
85.000	28000.0	99000.0	28000.0	.177	.181	.0	.00361	85.00	928.22	237.61	1739.32
86.000	28000.0	99000.0	28000.0	.211	.216	.0	.00433	86.00	944.90	237.17	1739.32
87.000	28000.0	99000.0	28000.0	.261	.265	.0	.00535	87.01	971.36	236.52	1739.32
88.000	28000.0	99000.0	28000.0	.335	.340	.0	.00689	88.01	1015.91	235.48	1739.32
89.200	28000.0	99000.0	28000.0	.490	.496	.0	.01111	89.21	1119.83	233.36	1739.32
89.400	28000.0	99000.0	28000.0	.528	.534	.0	.01089	89.41	1146.66	232.86	1739.32
89.600	28000.0	99000.0	28000.0	.571	.577	.0	.01176	89.61	1177.51	232.33	1739.32
89.800	28000.0	99000.0	28000.0	.619	.626	.0	.01275	89.81	1212.96	231.75	1739.32
90.000	28000.0	99000.0	28000.0	.649	.682	.2	.01387	90.01	1253.22	231.14	1706.22
90.200	28000.0	99000.0	27965.8	.712	.746	5.9	.01514	90.22	1302.90	230.50	1717.94
90.400	28000.0	99000.0	27843.2	.786	.820	12.3	.01661	90.42	1353.64	229.86	1751.32
90.600	28000.0	99000.0	27647.2	.871	.906	19.6	.01830	90.62	1417.16	229.23	1807.07
90.800	28000.0	99000.0	27372.7	.970	1.016	28.1	.02028	90.82	1495.39	228.62	1887.40
91.000	28000.0	99000.0	27019.6	1.086	1.123	38.2	.02260	91.02	1580.60	228.04	1995.54
91.200	28000.0	99000.0	26588.0	1.224	1.261	50.5	.02534	91.23	1702.16	227.50	2136.69
91.400	28000.0	99000.0	26077.6	1.389	1.426	65.5	.02861	91.43	1838.66	227.01	2316.42
91.600	28000.0	99000.0	25488.3	1.588	1.622	84.2	.03252	91.63	2020.73	226.57	2543.05
91.800	28000.0	99000.0	24819.6	1.837	1.861	111.0	.03827	91.84	2207.43	226.01	2830.32
92.000	28000.0	99000.0	24071.7	2.134	2.152	138.9	.04349	92.04	2457.80	225.35	3190.33
92.200	28000.0	99000.0	23243.6	2.514	2.513	179.5	.05117	92.25	2790.28	224.48	3650.36
92.400	28000.0	99000.0	22334.6	3.006	2.968	235.6	.06148	92.46	3161.30	223.18	4243.62
92.600	28000.0	99000.0	21344.7	3.626	3.538	305.4	.07341	92.67	3656.89	222.02	5010.66
92.800	28000.0	99000.0	20272.4	4.450	4.264	397.3	.08874	92.89	4270.26	220.88	6021.71
93.000	28000.0	99000.0	19116.2	5.540	5.199	526.5	.10853	93.11	5105.07	219.71	7380.05
93.200	28000.0	99000.0	17874.0	7.015	6.421	701.5	.13446	93.33	6169.13	218.52	9246.56
93.400	28000.0	99000.0	16544.1	9.072	8.017	935.5	.16723	93.57	7531.18	217.83	11855.93
93.600	28000.0	99000.0	15121.7	12.069	10.145	1266.1	.21129	94.01	9416.65	217.34	15663.93
93.800	28000.0	99000.0	13600.8	16.095	13.337	1740.2	.27133	94.37	11911.67	216.97	21412.39
94.000	28000.0	99000.0	11989.0	21.162	16.708	2146.4	.31847	94.32	15305.78	219.29	28849.06
94.200	28000.0	99000.0	10291.7	28.506	21.224	2762.2	.38543	94.59	19416.57	226.12	39791.44
94.400	28000.0	99000.0	8491.4	38.485	26.929	3414.2	.45248	94.85	25128.60	234.43	54871.74
94.600	28000.0	99000.0	6580.7	52.572	34.262	4284.5	.53354	95.14	32211.81	243.96	77343.39

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/50 M  
THE APPARENT AND ASTRONOMIC ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	TIEFF (11)	PITAN (12)
81.000	29000.0	99000.0	29000.0	.090	.093	.0	.00183	81.00	773.04	240.82	1493.30
82.000	29000.0	99000.0	29000.0	.101	.103	.0	.00205	82.00	776.49	240.71	1493.30
83.000	29000.0	99000.0	29000.0	.114	.116	.0	.00232	83.00	781.19	240.57	1493.30
84.000	29000.0	99000.0	29000.0	.130	.133	.0	.00266	84.00	787.76	240.36	1493.30
85.000	29000.0	99000.0	29000.0	.152	.155	.0	.00311	85.00	797.28	240.07	1493.30
86.000	29000.0	99000.0	29000.0	.181	.185	.0	.00372	86.00	811.66	239.65	1493.30
87.000	29000.0	99000.0	29000.0	.224	.228	.0	.00460	87.00	834.43	239.01	1493.30
88.000	29000.0	99000.0	29000.0	.288	.292	.0	.00594	88.01	872.71	238.00	1493.30
89.200	29000.0	99000.0	29000.0	.421	.425	.0	.00879	89.21	961.94	235.83	1493.30
89.400	29000.0	99000.0	29000.0	.453	.457	.0	.00948	89.41	984.99	235.29	1493.30
89.600	29000.0	99000.0	29000.0	.490	.494	.0	.01026	89.61	1011.52	234.67	1493.30
89.800	29000.0	99000.0	29000.0	.531	.536	.0	.01113	89.81	1042.01	233.97	1493.30
90.000	29000.0	99000.0	29000.0	.555	.584	.1	.01210	90.01	1076.65	233.20	1462.86
90.200	29000.0	99000.0	28960.8	.609	.639	5.1	.01319	90.21	1119.38	232.36	1472.74
90.400	29000.0	99000.0	28843.3	.672	.702	10.6	.01442	90.41	1162.98	231.50	1501.16
90.600	29000.0	99000.0	28647.4	.745	.776	16.9	.01585	90.62	1217.53	230.65	1548.17
90.800	29000.0	99000.0	28373.1	.830	.862	24.2	.01752	90.82	1284.66	229.83	1617.21
91.000	29000.0	99000.0	28220.4	.929	.963	32.9	.01949	91.02	1357.77	229.06	1709.44
91.200	29000.0	99000.0	27589.1	1.047	1.082	43.4	.02182	91.22	1462.04	228.36	1829.80
91.400	29000.0	99000.0	27079.1	1.188	1.223	56.3	.02461	91.42	1579.10	227.72	1982.97
91.600	29000.0	99000.0	26490.4	1.357	1.392	72.2	.02795	91.63	1735.18	227.16	2175.93
91.800	29000.0	99000.0	25822.6	1.563	1.596	92.3	.03199	91.83	1894.93	226.66	2418.80
92.000	29000.0	99000.0	25075.9	1.815	1.842	117.7	.03691	92.04	2108.31	226.22	2723.62
92.200	29000.0	99000.0	24249.3	2.134	2.149	152.2	.04347	92.24	2391.45	225.42	3111.01
92.400	29000.0	99000.0	23342.5	2.536	2.530	196.8	.05154	92.45	2705.90	224.54	3604.87
92.600	29000.0	99000.0	22354.5	3.061	3.014	259.2	.06241	92.66	3127.03	223.21	4246.03
92.800	29000.0	99000.0	21285.3	3.733	3.627	337.2	.07516	92.88	3648.02	222.00	5082.51
93.000	29000.0	99000.0	20133.1	4.636	4.415	443.5	.09173	93.09	4355.01	220.80	6198.18
93.200	29000.0	99000.0	18896.0	5.863	5.445	602.3	.11549	93.32	5255.72	219.53	7735.60
93.400	29000.0	99000.0	17572.3	7.523	6.797	791.7	.14210	93.54	6412.93	218.37	9839.95
93.600	29000.0	99000.0	16158.9	9.907	8.586	1066.6	.17896	93.78	8007.72	217.71	12869.58
93.800	29000.0	99000.0	14650.5	13.474	11.004	1650.2	.22907	94.03	10114.34	217.23	17408.20
94.000	29000.0	99000.0	13039.6	18.348	14.337	2030.7	.29830	94.30	12929.71	216.89	24323.05
94.200	29000.0	99000.0	11352.9	23.888	18.308	2433.8	.34120	94.54	16676.02	222.18	32886.12
94.400	29000.0	99000.0	9565.1	31.990	23.364	2974.3	.39740	94.80	21487.92	229.60	45098.80
94.600	29000.0	99000.0	7669.9	43.636	29.836	3669.0	.46722	95.07	27943.80	238.51	62831.06
94.800	29000.0	99000.0	5654.8	61.815	38.371	4849.8	.58161	95.38	36557.27	248.59	92275.89

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	30000.0	99000.0	30000.0	.078	.080	.0	.00151	81.00	664.48	243.67	1282.09
82.000	30000.0	99000.0	30000.0	.087	.089	.0	.00168	82.00	667.46	243.57	1282.09
83.000	30000.0	99000.0	30000.0	.098	.100	.0	.00190	83.00	671.51	243.43	1282.09
84.000	30000.0	99000.0	30000.0	.112	.114	.0	.00218	84.00	677.18	243.25	1282.09
85.000	30000.0	99000.0	30000.0	.130	.133	.0	.00254	85.00	685.39	242.98	1282.09
86.000	30000.0	99000.0	30000.0	.156	.159	.0	.00304	86.00	697.76	242.60	1282.09
87.000	30000.0	99000.0	30000.0	.192	.195	.0	.00374	87.00	717.32	242.03	1282.09
88.000	30000.0	99000.0	30000.0	.247	.250	.0	.00481	88.00	750.08	241.16	1282.09
89.200	30000.0	99000.0	30000.0	.361	.363	.0	.00698	89.21	825.92	239.58	1282.09
89.400	30000.0	99000.0	30000.0	.389	.390	.0	.00750	89.41	845.39	239.25	1282.09
89.600	30000.0	99000.0	30000.0	.420	.421	.0	.00808	89.61	867.73	238.91	1282.09
89.800	30000.0	99000.0	30000.0	.456	.455	.0	.00875	89.81	893.35	238.56	1282.09
90.000	30000.0	99000.0	30000.0	.445	.495	.1	.00950	90.01	922.42	238.21	1256.35
90.200	30000.0	99000.0	29969.7	.492	.541	4.6	.01237	90.21	958.73	236.93	1264.42
90.400	30000.0	99000.0	29842.6	.576	.596	10.9	.01563	90.42	997.06	235.07	1287.21
90.600	30000.0	99000.0	29646.3	.638	.662	15.8	.01580	90.62	1045.24	232.98	1327.32
90.800	30000.0	99000.0	29372.2	.711	.737	21.5	.01632	90.82	1103.45	231.66	1386.16
91.000	30000.0	99000.0	29019.7	.795	.825	28.7	.01763	91.02	1166.41	230.52	1464.85
91.200	30000.0	99000.0	28588.7	.896	.928	37.6	.01944	91.22	1256.04	229.53	1567.56
91.400	30000.0	99000.0	28079.2	1.017	1.049	48.5	.02170	91.42	1356.53	228.67	1698.22
91.600	30000.0	99000.0	27491.0	1.161	1.195	62.2	.02448	91.62	1490.46	227.92	1862.71
91.800	30000.0	99000.0	26823.9	1.336	1.369	79.3	.02788	91.83	1627.46	227.27	2069.58
92.000	30000.0	99000.0	26077.9	1.550	1.581	101.0	.03205	92.03	1810.45	226.72	2328.87
92.200	30000.0	99000.0	25252.6	1.815	1.840	128.8	.03717	92.24	2027.50	226.24	2655.71
92.400	30000.0	99000.0	24347.3	2.153	2.164	166.9	.04406	92.44	2319.82	225.45	3070.68
92.600	30000.0	99000.0	23361.7	2.583	2.569	216.6	.05260	92.65	2676.75	224.54	3605.17
92.800	30000.0	99000.0	22294.6	3.150	3.090	286.2	.06413	92.86	3119.66	223.16	4303.70
93.000	30000.0	99000.0	21145.8	3.895	3.756	374.6	.07791	93.08	3719.51	221.91	5226.13
93.200	30000.0	99000.0	19913.2	4.898	4.623	506.2	.09763	93.30	4482.09	220.62	6483.38
93.400	30000.0	99000.0	18594.5	6.274	5.767	676.5	.12185	93.52	5463.97	219.14	8212.86
93.600	30000.0	99000.0	17188.6	8.187	7.278	901.7	.15212	93.75	6815.18	218.19	10643.41
93.800	30000.0	99000.0	15690.5	11.003	9.307	1228.1	.19403	93.99	8596.65	217.56	14225.50
94.000	30000.0	99000.0	14096.1	15.104	12.087	1700.1	.25170	94.25	10974.78	217.12	19718.51
94.200	30000.0	99000.0	12474.3	20.409	15.754	2193.7	.30775	94.51	14260.71	218.81	27344.90
94.400	30000.0	99000.0	10627.5	26.884	20.246	2648.6	.35528	94.76	18508.79	225.08	37463.20
94.600	30000.0	99000.0	8745.6	35.883	25.929	3113.0	.40233	95.00	24165.70	233.24	51100.68
94.800	30000.0	99000.0	6751.7	49.251	33.311	3904.3	.48070	95.28	31251.37	242.95	72394.59

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
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THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	31000.0	99000.0	31000.0	.067	.069	.0	.00130	81.00	574.75	245.23	1108.84
82.000	31000.0	99000.0	31000.0	.075	.077	.0	.00145	82.00	577.34	245.13	1108.84
83.000	31000.0	99000.0	31000.0	.084	.087	.0	.00164	83.00	580.86	244.99	1108.84
84.000	31000.0	99000.0	31000.0	.096	.099	.0	.00188	84.00	585.79	244.80	1108.84
85.000	31000.0	99000.0	31000.0	.112	.115	.0	.00220	85.00	592.91	244.53	1108.84
86.000	31000.0	99000.0	31000.0	.134	.137	.0	.00263	86.00	603.64	244.12	1108.84
87.000	31000.0	99000.0	31000.0	.165	.169	.0	.00324	87.00	620.59	243.51	1108.84
88.000	31000.0	99000.0	31000.0	.212	.216	.0	.00416	88.00	648.95	242.57	1108.84
89.200	31000.0	99000.0	31000.0	.307	.314	.0	.00605	89.21	714.49	240.76	1108.84
89.400	31000.0	99000.0	31000.0	.330	.337	.0	.00650	89.41	731.30	240.38	1108.84
89.600	31000.0	99000.0	31000.0	.357	.363	.0	.00701	89.61	750.59	239.97	1108.84
89.800	31000.0	99000.0	31000.0	.386	.393	.0	.00758	89.81	772.71	239.55	1108.84
90.000	31000.0	99000.0	31000.0	.401	.407	.1	.00823	90.01	797.79	239.12	1084.17
90.200	31000.0	99000.0	30960.9	.439	.467	3.4	.00898	90.21	828.59	238.68	1090.92
90.400	31000.0	99000.0	30843.5	.484	.511	7.2	.00983	90.41	860.12	238.24	1110.78
90.600	31000.0	99000.0	30647.9	.534	.563	11.5	.01082	90.61	899.37	237.81	1143.67
90.800	31000.0	99000.0	30374.0	.593	.623	16.5	.01196	90.81	947.46	237.40	1191.62
91.000	31000.0	99000.0	30021.8	.663	.694	22.4	.01330	91.01	999.77	237.00	1256.45
91.200	31000.0	99000.0	29589.8	.775	.788	32.2	.01788	91.22	1078.01	232.84	1343.25
91.400	31000.0	99000.0	29080.6	.877	.895	42.8	.01902	91.42	1165.17	231.01	1454.43
91.600	31000.0	99000.0	28492.8	.999	1.021	54.0	.02120	91.62	1280.50	229.67	1594.65
91.800	31000.0	99000.0	27826.3	1.148	1.172	68.5	.02404	91.82	1398.22	228.62	1770.95
92.000	31000.0	99000.0	27000.9	1.330	1.354	86.9	.02757	92.03	1555.28	227.76	1991.71
92.200	31000.0	99000.0	26256.5	1.544	1.577	110.6	.03194	92.23	1741.48	227.06	2268.92
92.400	31000.0	99000.0	25352.6	1.835	1.851	141.3	.03736	92.44	1990.90	226.47	2619.71
92.600	31000.0	99000.0	24368.6	2.195	2.196	183.7	.04468	92.64	2295.09	225.62	3068.55
92.800	31000.0	99000.0	23304.1	2.659	2.632	239.3	.05379	92.85	2670.54	224.64	3650.01
93.000	31000.0	99000.0	22157.7	3.286	3.197	317.5	.06615	93.07	3179.98	223.16	4418.72
93.200	31000.0	99000.0	20928.7	4.109	3.929	426.4	.08249	93.28	3826.57	221.81	5452.41
93.400	31000.0	99000.0	19615.1	5.230	4.892	569.5	.10292	93.50	4658.08	220.28	6864.61
93.600	31000.0	99000.0	18214.8	6.805	6.171	765.8	.12957	93.73	5803.20	218.89	8848.93
93.800	31000.0	99000.0	16725.3	9.552	7.881	1036.5	.16450	93.96	7311.46	218.02	11706.33
94.000	31000.0	99000.0	15140.9	12.443	10.209	1428.2	.21269	94.21	9322.79	217.43	16024.65
94.200	31000.0	99000.0	13454.0	17.216	13.447	2002.9	.27991	94.48	12172.35	217.01	22767.02
94.400	31000.0	99000.0	11667.4	22.598	17.435	2777.4	.30811	94.71	15873.55	221.25	30672.40
94.600	31000.0	99000.0	9813.8	30.281	22.525	3534.1	.35341	94.95	20665.36	228.09	42137.17
94.800	31000.0	99000.0	7833.1	42.379	29.165	4334.0	.43616	95.24	27164.48	237.16	60527.29
95.000	31000.0	99000.0	5740.4	60.840	37.843	4734.9	.54994	95.55	35951.49	248.06	90130.51

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	32000.0	99000.0	32000.0	.058	.660	.0	.00113	81.00	497.27	247.05	958.23
82.000	32000.0	99000.0	32000.0	.065	.666	.0	.00126	82.00	499.52	246.95	958.23
83.000	32000.0	99000.0	32000.0	.073	.675	.0	.00142	83.00	502.58	246.81	958.23
84.000	32000.0	99000.0	32000.0	.083	.686	.0	.00163	84.00	506.86	246.62	958.23
85.000	32000.0	99000.0	32000.0	.097	.700	.0	.00190	85.00	513.05	246.34	958.23
86.000	32000.0	99000.0	32000.0	.116	.719	.0	.00228	86.00	522.36	245.93	958.23
87.000	32000.0	99000.0	32000.0	.143	.746	.0	.00281	87.00	537.05	245.29	958.23
88.000	32000.0	99000.0	32000.0	.183	.787	.0	.00361	88.00	561.60	244.28	958.23
89.200	32000.0	99000.0	32000.0	.266	.871	.0	.00525	89.21	618.25	242.25	958.23
89.400	32000.0	99000.0	32000.0	.286	.891	.0	.00564	89.41	632.77	241.80	958.23
89.600	32000.0	99000.0	32000.0	.308	.914	.0	.00608	89.61	649.43	241.32	958.23
89.800	32000.0	99000.0	32000.0	.334	.940	.0	.00658	89.81	668.52	240.81	958.23
90.000	32000.0	99000.0	32000.0	.345	.969	.0	.00714	90.01	690.17	240.28	935.55
90.200	32000.0	99000.0	31960.9	.379	.993	3.0	.00779	90.21	716.75	239.74	941.31
90.400	32000.0	99000.0	31843.6	.417	.993	6.2	.00852	90.41	743.95	239.20	958.38
90.600	32000.0	99000.0	31648.0	.460	.987	9.9	.00937	90.61	777.82	238.66	986.67
90.800	32000.0	99000.0	31374.2	.511	.939	14.3	.01036	90.81	819.33	238.15	1027.93
91.000	32000.0	99000.0	31022.1	.571	.800	19.4	.01152	91.01	864.47	237.65	1083.73
91.200	32000.0	99000.0	30591.7	.641	.671	25.5	.01287	91.21	928.30	237.19	1155.86
91.400	32000.0	99000.0	30083.0	.724	.755	33.0	.01448	91.41	999.73	236.77	1247.21
91.600	32000.0	99000.0	29494.3	.854	.870	49.3	.01910	91.62	1099.72	232.53	1365.88
91.800	32000.0	99000.0	28828.2	.981	1.002	59.8	.02092	91.82	1201.34	230.56	1515.94
92.000	32000.0	99000.0	28083.4	1.136	1.159	75.2	.02380	92.02	1336.30	229.18	1704.02
92.200	32000.0	99000.0	27259.7	1.327	1.351	95.3	.02749	92.23	1496.09	228.13	1939.98
92.400	32000.0	99000.0	26356.8	1.565	1.587	121.4	.03210	92.43	1709.99	227.30	2238.15
92.600	32000.0	99000.0	25374.3	1.865	1.879	155.5	.03788	92.64	1969.56	226.62	2616.73
92.800	32000.0	99000.0	24311.4	2.255	2.249	203.0	.04570	92.85	2289.57	225.70	3105.59
93.000	32000.0	99000.0	23167.8	2.774	2.723	265.7	.05554	93.06	2720.82	224.65	3743.03
93.200	32000.0	99000.0	21941.6	3.456	3.343	360.3	.06987	93.27	3270.21	223.04	4602.08
93.400	32000.0	99000.0	20632.0	4.377	4.156	480.6	.08710	93.49	3975.45	221.44	5763.56
93.600	32000.0	99000.0	19237.4	5.668	5.231	643.8	.10934	93.71	4943.00	220.01	7375.50
93.800	32000.0	99000.0	17754.3	7.489	6.681	877.9	.13983	93.94	6148.59	218.63	9691.92
94.000	32000.0	99000.0	16179.8	10.173	8.638	1203.5	.18011	94.18	7925.78	217.83	13107.88
94.200	32000.0	99000.0	14507.0	14.159	11.343	1679.2	.23618	94.44	10203.99	217.28	18439.44
94.400	32000.0	99000.0	12739.1	18.928	14.957	2001.0	.27181	94.67	13566.07	218.25	25317.56
94.600	32000.0	99000.0	10874.3	25.076	19.573	2566.0	.33177	94.93	17888.79	223.59	35779.85
94.800	32000.0	99000.0	8926.6	36.372	25.523	3370.0	.41239	95.21	23554.83	231.92	51733.73
95.000	32000.0	99000.0	6832.2	50.564	33.111	4196.6	.49087	95.49	31017.60	242.22	74258.74

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.03 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	33000.0	99000.0	33000.0	.050	.052	.0	.00098	81.00	430.38	249.17	828.07
82.000	33000.0	99000.0	33000.0	.056	.057	.0	.00109	82.00	432.34	249.07	828.07
83.000	33000.0	99000.0	33000.0	.063	.065	.0	.00123	83.00	435.00	248.94	828.07
84.000	33000.0	99000.0	33000.0	.072	.074	.0	.00141	84.00	438.72	248.75	828.07
85.000	33000.0	99000.0	33000.0	.084	.086	.0	.00165	85.00	444.09	248.47	828.07
86.000	33000.0	99000.0	33000.0	.100	.103	.0	.00197	86.00	452.17	248.06	828.07
87.000	33000.0	99000.0	33000.0	.123	.126	.0	.00243	87.00	464.90	247.43	828.07
88.000	33000.0	99000.0	33000.0	.158	.161	.0	.00313	88.00	486.14	246.39	828.07
89.200	33000.0	99000.0	33000.0	.229	.234	.0	.00456	89.20	535.10	244.18	828.07
89.400	33000.0	99000.0	33000.0	.247	.251	.0	.00491	89.40	547.64	243.66	828.07
89.600	33000.0	99000.0	33000.0	.266	.271	.0	.00529	89.61	562.03	243.09	828.07
89.800	33000.0	99000.0	33000.0	.288	.293	.0	.00572	89.81	578.52	242.48	828.07
90.000	33000.0	99000.0	33000.0	.298	.319	.0	.00621	90.01	597.21	241.82	807.26
90.200	33000.0	99000.0	32960.9	.326	.348	2.6	.00677	90.21	620.15	241.14	812.19
90.400	33000.0	99000.0	32843.6	.359	.382	5.4	.00741	90.41	643.62	240.45	826.56
90.600	33000.0	99000.0	32648.1	.397	.421	8.6	.00814	90.61	672.85	239.77	851.21
90.800	33000.0	99000.0	32374.4	.441	.466	12.4	.00899	90.81	708.67	239.11	886.73
91.000	33000.0	99000.0	32222.4	.492	.518	16.8	.00998	91.01	747.62	238.49	934.78
91.200	33000.0	99000.0	31592.1	.553	.580	22.1	.01115	91.21	802.72	237.90	996.87
91.400	33000.0	99000.0	31083.6	.624	.653	28.5	.01254	91.41	864.38	237.37	1075.49
91.600	33000.0	99000.0	30496.6	.709	.740	36.5	.01418	91.61	945.94	236.88	1173.91
91.800	33000.0	99000.0	29830.2	.840	.848	61.2	.02060	91.82	1030.81	234.97	1299.57
92.000	33000.0	99000.0	29085.5	.971	.990	66.1	.02083	92.02	1148.09	231.31	1458.52
92.200	33000.0	99000.0	28262.3	1.134	1.156	82.5	.02375	92.22	1285.46	229.61	1659.44
92.400	33000.0	99000.0	27360.2	1.337	1.359	104.5	.02764	92.43	1468.99	228.38	1913.18
92.600	33000.0	99000.0	26378.7	1.591	1.611	133.6	.03256	92.63	1691.57	227.44	2234.84
92.800	33000.0	99000.0	25317.5	1.915	1.925	171.8	.03877	92.84	1964.68	226.70	2646.90
93.000	33000.0	99000.0	24175.6	2.339	2.327	225.3	.04719	93.05	2331.95	225.70	3181.78
93.200	33000.0	99000.0	22952.4	2.916	2.847	305.6	.05932	93.26	2796.71	224.55	3895.47
93.400	33000.0	99000.0	21646.0	3.676	3.536	406.7	.07386	93.47	3396.34	222.64	4855.47
93.600	33000.0	99000.0	20256.0	4.731	4.442	542.6	.09244	93.69	4166.02	221.16	6175.08
93.800	33000.0	99000.0	18778.6	6.243	5.666	761.1	.12110	93.92	5238.56	219.54	8082.78
94.000	33000.0	99000.0	17212.4	8.379	7.319	1017.4	.15286	94.15	6742.88	218.35	10801.86
94.200	33000.0	99000.0	15551.0	11.656	9.588	1412.7	.19974	94.40	8673.04	217.63	14976.33
94.400	33000.0	99000.0	13787.1	16.393	12.773	1997.9	.26583	94.67	11428.43	217.13	21641.47
94.600	33000.0	99000.0	11929.2	22.105	16.912	2351.7	.30341	94.90	15285.19	219.62	29961.12
94.800	33000.0	99000.0	9973.0	31.396	22.252	3171.2	.38579	95.19	20353.18	226.94	43867.53
95.000	33000.0	99000.0	7913.0	43.491	29.011	3870.6	.45224	95.45	26957.29	236.50	62505.32
95.200	33000.0	99000.0	5740.7	61.987	37.872	4949.5	.55034	95.75	35920.74	248.05	92412.79

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	34000.0	99000.0	34000.0	.043	.045	.0	.00084	81.00	372.65	251.64	715.60
82.000	34000.0	99000.0	34000.0	.048	.050	.0	.00094	82.00	374.35	251.54	715.60
83.000	34000.0	99000.0	34000.0	.054	.056	.0	.00107	83.00	376.67	251.42	715.60
84.000	34000.0	99000.0	34000.0	.062	.064	.0	.00122	84.00	379.90	251.24	715.60
85.000	34000.0	99000.0	34000.0	.072	.074	.0	.00143	85.00	384.56	250.99	715.60
86.000	34000.0	99000.0	34000.0	.086	.089	.0	.00171	86.00	391.57	250.60	715.60
87.000	34000.0	99000.0	34000.0	.106	.109	.0	.00211	87.00	402.59	250.00	715.60
88.000	34000.0	99000.0	34000.0	.137	.139	.0	.00272	88.00	420.93	249.02	715.60
89.200	34000.0	99000.0	34000.0	.198	.201	.0	.00399	89.20	463.14	246.80	715.60
89.400	34000.0	99000.0	34000.0	.213	.216	.0	.00431	89.40	473.97	246.24	715.60
89.600	34000.0	99000.0	34000.0	.230	.233	.0	.00465	89.60	486.40	245.59	715.60
89.800	34000.0	99000.0	34000.0	.249	.253	.0	.00504	89.81	500.65	244.85	715.60
90.000	34000.0	99000.0	34000.0	.256	.275	.0	.00547	90.01	516.81	244.03	696.54
90.200	34000.0	99000.0	33960.9	.281	.300	2.3	.00594	90.21	536.65	243.14	700.75
90.400	34000.0	99000.0	33843.6	.309	.329	4.7	.00648	90.41	556.93	242.21	713.11
90.600	34000.0	99000.0	33648.2	.342	.363	7.5	.00710	90.61	582.17	241.30	734.34
90.800	34000.0	99000.0	33374.5	.380	.422	10.8	.00782	90.81	613.09	240.41	764.93
91.000	34000.0	99000.0	33022.6	.424	.448	14.6	.00867	91.01	646.70	239.58	806.31
91.200	34000.0	99000.0	32592.5	.476	.501	19.1	.00967	91.21	694.26	238.82	859.79
91.400	34000.0	99000.0	32084.0	.538	.564	24.7	.01086	91.41	747.48	238.14	927.48
91.600	34000.0	99000.0	31497.2	.611	.639	31.6	.01228	91.61	817.89	237.52	1012.18
91.800	34000.0	99000.0	30832.1	.700	.729	40.1	.01399	91.81	889.92	236.97	1117.99
92.000	34000.0	99000.0	30088.4	.807	.838	50.8	.01605	92.02	985.32	236.50	1249.47
92.200	34000.0	99000.0	29264.5	.969	.987	73.1	.02094	92.22	1104.28	231.88	1420.27
92.400	34000.0	99000.0	28362.9	1.142	1.164	90.5	.02390	92.42	1262.13	229.88	1636.19
92.600	34000.0	99000.0	27332.3	1.359	1.380	115.0	.02803	92.63	1453.10	228.51	1909.79
92.800	34000.0	99000.0	26322.1	1.633	1.650	147.6	.03332	92.83	1687.29	227.49	2259.02
93.000	34000.0	99000.0	25182.1	1.985	1.991	190.9	.04006	93.04	2000.45	226.70	2710.01
93.200	34000.0	99000.0	23961.0	2.460	2.431	255.1	.04975	93.25	2396.02	225.62	3304.30
93.400	34000.0	99000.0	22657.5	3.099	3.011	347.5	.06315	93.46	2904.19	223.94	4105.77
93.600	34000.0	99000.0	21271.3	3.966	3.778	458.5	.07830	93.68	3558.14	222.33	5192.18
93.800	34000.0	99000.0	19799.3	5.192	4.808	639.7	.10213	93.90	4466.16	220.69	6742.38
94.000	34000.0	99000.0	18239.2	6.942	6.207	864.4	.13023	94.13	5739.95	219.06	8953.49
94.200	34000.0	99000.0	16587.6	9.541	8.117	1192.1	.16929	94.37	7377.22	218.07	12264.65
94.400	34000.0	99000.0	14837.5	13.644	10.782	1677.3	.22446	94.62	9705.15	217.42	17494.01
94.600	34000.0	99000.0	12979.3	19.142	14.539	2271.4	.28909	94.89	13068.64	217.01	25430.27
94.800	34000.0	99000.0	11037.4	27.237	19.307	3035.9	.36555	95.17	17337.07	222.91	37327.22
95.000	34000.0	99000.0	8987.9	37.957	25.405	3777.2	.43595	95.44	23370.50	231.49	53942.69
95.200	34000.0	99000.0	6632.9	51.779	33.136	4390.5	.49150	95.69	30990.69	242.21	75999.34

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## LATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SC M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	35000.0	99000.0	35000.0	.037	.039	.0	.00070	81.00	323.13	254.49	618.40
82.000	35000.0	99000.0	35000.0	.042	.043	.0	.00078	82.00	324.61	254.41	618.40
83.000	35000.0	99000.0	35000.0	.047	.048	.0	.00088	83.00	326.62	254.30	618.40
84.000	35000.0	99000.0	35000.0	.054	.055	.0	.00100	84.00	329.43	254.15	618.40
85.000	35000.0	99000.0	35000.0	.063	.064	.0	.00117	85.00	333.48	253.94	618.40
86.000	35000.0	99000.0	35000.0	.075	.077	.0	.00140	86.00	339.55	253.61	618.40
87.000	35000.0	99000.0	35000.0	.092	.094	.0	.00172	87.00	349.07	253.10	618.40
88.000	35000.0	99000.0	35000.0	.118	.120	.0	.00220	88.00	364.86	252.31	618.40
89.200	35000.0	99000.0	35000.0	.171	.173	.0	.00318	89.20	400.87	250.77	618.40
89.400	35000.0	99000.0	35000.0	.184	.186	.0	.00341	89.40	410.04	250.45	618.40
89.600	35000.0	99000.0	35000.0	.199	.200	.0	.00367	89.60	420.53	250.11	618.40
89.800	35000.0	99000.0	35000.0	.215	.216	.0	.00396	89.80	432.53	249.75	618.40
90.000	35000.0	99000.0	35000.0	.227	.234	.0	.00430	90.00	446.13	249.39	602.23
90.200	35000.0	99000.0	34960.8	.206	.256	2.1	.00565	90.21	462.98	248.04	605.70
90.400	35000.0	99000.0	34843.3	.252	.281	5.0	.00718	90.41	480.84	246.06	615.96
90.600	35000.0	99000.0	34647.6	.295	.312	7.2	.00721	90.61	503.33	243.81	633.61
90.800	35000.0	99000.0	34374.0	.327	.346	9.7	.00739	90.81	530.33	242.39	659.94
91.000	35000.0	99000.0	34222.2	.366	.386	12.8	.00794	91.01	559.46	241.16	695.59
91.200	35000.0	99000.0	33592.1	.410	.433	16.7	.00871	91.21	600.60	240.09	741.37
91.400	35000.0	99000.0	33383.8	.464	.487	21.5	.00967	91.41	646.57	239.16	799.95
91.600	35000.0	99000.0	32497.2	.527	.553	27.4	.01086	91.61	707.38	238.35	872.89
91.800	35000.0	99000.0	31832.2	.603	.630	34.7	.01230	91.81	769.56	237.64	963.98
92.000	35000.0	99000.0	30266.8	.695	.724	44.0	.01405	92.01	851.93	237.04	1077.10
92.200	35000.0	99000.0	30266.8	.807	.838	55.7	.01620	92.21	949.15	236.52	1217.79
92.400	35000.0	99000.0	29364.6	.976	.993	80.9	.02132	92.42	1084.24	232.24	1400.40
92.600	35000.0	99000.0	28384.6	1.161	1.182	99.6	.02437	92.62	1248.55	230.00	1633.06
92.800	35000.0	99000.0	27325.3	1.394	1.414	127.1	.02880	92.83	1449.49	228.53	1930.00
93.000	35000.0	99000.0	26186.4	1.693	1.707	164.0	.03454	93.03	1717.96	227.46	2312.76
93.200	35000.0	99000.0	24967.3	2.087	2.080	216.1	.04233	93.24	2054.96	226.63	2811.90
93.400	35000.0	99000.0	23666.5	2.611	2.569	289.1	.05286	93.45	2466.65	225.25	3477.58
93.600	35000.0	99000.0	22283.2	3.337	3.218	389.0	.06664	93.67	3042.09	223.56	4381.64
93.800	35000.0	99000.0	20815.7	4.339	4.086	539.1	.08642	93.89	3812.19	221.86	5650.20
94.000	35000.0	99000.0	19261.7	5.770	5.262	727.1	.11000	94.11	4831.44	220.17	7444.59
94.200	35000.0	99000.0	17617.4	7.866	6.881	1009.5	.14392	94.34	6279.55	218.65	10114.51
94.400	35000.0	99000.0	15878.7	11.086	9.119	1412.9	.19006	94.59	8249.23	217.80	14218.03
94.600	35000.0	99000.0	14036.6	16.094	12.291	2016.4	.25585	94.86	10966.31	217.23	20889.03
94.800	35000.0	99000.0	12093.5	22.802	16.629	2729.2	.32893	95.13	14861.28	219.27	30869.30
95.000	35000.0	99000.0	10057.1	32.197	22.116	3537.0	.40621	95.41	19983.03	226.74	45517.86
95.200	35000.0	99000.0	7913.5	44.016	29.034	4049.5	.45288	95.65	26934.74	236.49	63917.09
95.400	35000.0	99000.0	5652.3	67.136	38.485	5542.8	.58431	95.98	36275.18	248.56	100044.70

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	36000.0	99000.0	36000.0	.033	.034	.0	.00061	81.00	282.12	255.95	538.35
82.000	36000.0	99000.0	36000.0	.036	.037	.0	.00068	82.00	283.42	255.87	538.35
83.000	36000.0	99000.0	36000.0	.041	.042	.0	.00076	83.00	285.19	255.77	538.35
84.000	36000.0	99000.0	36000.0	.047	.048	.0	.00088	84.00	287.65	255.62	538.35
85.000	36000.0	99000.0	36000.0	.054	.056	.0	.00102	85.00	291.19	255.41	538.35
86.000	36000.0	99000.0	36000.0	.065	.067	.0	.00122	86.00	296.50	255.08	538.35
87.000	36000.0	99000.0	36000.0	.079	.082	.0	.00150	87.00	304.82	254.55	538.35
88.000	36000.0	99000.0	36000.0	.102	.105	.0	.00192	88.00	318.57	253.70	538.35
89.200	36000.0	99000.0	36000.0	.147	.151	.0	.00277	89.20	349.83	251.97	538.35
89.400	36000.0	99000.0	36000.0	.157	.162	.0	.00298	89.40	357.77	251.59	538.35
89.600	36000.0	99000.0	36000.0	.170	.174	.0	.00320	89.60	366.85	251.19	538.35
89.800	36000.0	99000.0	36000.0	.183	.188	.0	.00346	89.80	377.24	250.76	538.35
90.000	36000.0	99000.0	36000.0	.198	.204	.0	.00375	90.00	389.01	250.33	523.04
90.200	36000.0	99000.0	35960.9	.205	.222	1.5	.00408	90.20	403.39	249.88	526.01
90.400	36000.0	99000.0	35843.7	.225	.243	3.2	.00446	90.40	418.14	249.43	534.80
90.600	36000.0	99000.0	35648.3	.249	.267	5.2	.00489	90.60	436.42	248.99	549.94
90.800	36000.0	99000.0	35374.8	.275	.295	7.4	.00539	90.81	458.75	248.56	571.72
91.000	36000.0	99000.0	35023.1	.307	.327	10.0	.00598	91.01	483.01	248.16	601.14
91.200	36000.0	99000.0	34592.4	.358	.370	15.9	.00812	91.21	519.12	243.68	639.55
91.400	36000.0	99000.0	34084.2	.403	.419	19.2	.00855	91.41	559.29	241.69	689.68
91.600	36000.0	99000.0	33497.7	.457	.476	24.0	.00948	91.61	612.01	240.25	752.75
91.800	36000.0	99000.0	32832.9	.523	.543	30.2	.01069	91.81	665.78	239.11	831.17
92.000	36000.0	99000.0	32089.7	.602	.625	38.2	.01218	92.01	736.96	238.18	928.54
92.200	36000.0	99000.0	31268.0	.698	.723	48.2	.01402	92.21	820.94	237.41	1049.57
92.400	36000.0	99000.0	30367.7	.817	.844	61.1	.01629	92.42	932.42	236.78	1200.94
92.600	36000.0	99000.0	29387.1	.994	1.038	89.1	.02162	92.62	1072.77	232.55	1397.35
92.800	36000.0	99000.0	28328.6	1.193	1.210	110.0	.02490	92.82	1245.68	230.12	1649.68
93.000	36000.0	99000.0	27190.7	1.447	1.462	141.1	.02972	93.03	1475.96	228.56	1974.92
93.200	36000.0	99000.0	25972.9	1.775	1.783	183.3	.03600	93.24	1764.73	227.44	2397.13
93.400	36000.0	99000.0	24674.2	2.214	2.196	245.3	.04494	93.44	2132.26	226.34	2955.10
93.600	36000.0	99000.0	23294.0	2.802	2.741	325.6	.05595	93.66	2603.49	225.04	3704.53
93.800	36000.0	99000.0	21829.9	3.642	3.477	455.7	.07322	93.87	3257.46	223.11	4754.43
94.000	36000.0	99000.0	20260.9	4.859	4.469	613.0	.09300	94.09	4121.71	221.33	6220.95
94.200	36000.0	99000.0	18642.9	6.528	5.836	864.0	.12333	94.32	5347.81	219.50	8395.45
94.400	36000.0	99000.0	16913.6	9.080	7.723	1193.7	.16119	94.56	7016.68	218.29	11646.63
94.600	36000.0	99000.0	15085.2	13.173	10.380	1694.6	.21615	94.82	9314.67	217.55	16864.88
94.800	36000.0	99000.0	13147.3	19.112	14.213	2456.1	.29575	95.10	12678.92	217.04	25494.04
95.000	36000.0	99000.0	11123.4	27.270	19.079	3124.9	.36016	95.36	17167.99	222.76	37343.07
95.200	36000.0	99000.0	8988.9	38.847	25.425	3954.8	.43697	95.64	23351.07	231.49	55175.71
95.400	36000.0	99000.0	6752.9	52.817	33.392	4472.7	.48249	95.88	31171.13	242.92	77491.63

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	37000.0	99000.0	37000.0	.028	.029	.0	.00353	81.00	246.61	257.64	468.29
82.000	37000.0	99000.0	37000.0	.031	.033	.0	.00059	82.00	247.75	257.57	468.29
83.000	37000.0	99000.0	37000.0	.035	.037	.0	.00067	83.00	249.30	257.47	468.29
84.000	37000.0	99000.0	37000.0	.041	.042	.0	.00076	84.00	251.46	257.33	468.29
85.000	37000.0	99000.0	37000.0	.047	.049	.0	.00089	85.00	254.57	257.12	468.29
86.000	37000.0	99000.0	37000.0	.056	.058	.0	.00106	86.00	259.23	256.80	468.29
87.000	37000.0	99000.0	37000.0	.069	.071	.0	.00131	87.00	266.51	256.28	468.29
88.000	37000.0	99000.0	37000.0	.088	.091	.0	.00168	88.00	278.53	255.40	468.29
89.200	37000.0	99000.0	37000.0	.128	.131	.0	.00242	89.20	305.67	253.48	468.29
89.400	37000.0	99000.0	37000.0	.137	.141	.0	.00260	89.40	312.54	253.04	468.29
89.800	37000.0	99000.0	37000.0	.159	.164	.0	.00280	89.80	320.40	252.57	468.29
90.000	37000.0	99000.0	37000.0	.163	.177	.0	.00328	90.00	329.38	252.06	468.29
90.400	37000.0	99000.0	36960.9	.178	.193	1.3	.00356	90.40	351.97	250.97	456.80
90.600	37000.0	99000.0	36843.7	.195	.211	2.8	.00389	90.60	364.70	250.42	464.43
90.800	37000.0	99000.0	36648.3	.216	.232	4.5	.00427	90.80	380.52	249.87	477.56
91.000	37000.0	99000.0	36374.8	.239	.256	6.5	.00471	91.00	399.84	249.33	496.46
91.200	37000.0	99000.0	36023.1	.266	.284	8.7	.00521	91.20	420.85	248.83	521.99
91.400	37000.0	99000.0	35593.2	.298	.317	11.5	.00581	91.40	450.38	248.35	554.66
91.600	37000.0	99000.0	35085.1	.335	.356	14.8	.00650	91.60	483.36	247.91	596.12
91.800	37000.0	99000.0	34498.1	.394	.408	22.2	.00864	91.80	529.07	243.34	649.27
92.000	37000.0	99000.0	33633.4	.450	.467	33.3	.01060	92.00	576.07	241.21	716.74
92.200	37000.0	99000.0	32268.9	.601	.624	41.9	.01216	92.20	637.65	239.73	800.56
92.400	37000.0	99000.0	31368.9	.703	.728	53.0	.01411	92.40	710.19	238.59	904.71
92.600	37000.0	99000.0	30390.2	.830	.857	67.3	.01653	92.60	806.48	237.68	1034.93
92.800	37000.0	99000.0	29331.2	1.019	1.033	97.9	.02200	92.80	922.55	236.95	1198.07
93.000	37000.0	99000.0	28194.1	1.235	1.252	122.0	.02567	93.00	1070.27	232.55	1411.20
93.200	37000.0	99000.0	26977.4	1.514	1.528	157.7	.03097	93.20	1268.28	230.06	1687.53
93.400	37000.0	99000.0	25680.5	1.879	1.881	206.3	.03792	93.40	1515.92	228.48	2046.04
93.600	37000.0	99000.0	24302.4	2.372	2.343	276.2	.04755	93.60	1830.22	227.34	2516.02
93.800	37000.0	99000.0	22841.6	3.068	2.961	391.3	.06282	93.80	2231.78	226.13	3144.99
94.000	37000.0	99000.0	21296.6	4.024	3.801	518.1	.07879	94.00	2785.79	224.57	4016.19
94.200	37000.0	99000.0	19664.7	5.429	4.950	728.1	.10424	94.20	3520.03	222.53	5220.13
94.400	37000.0	99000.0	17942.7	7.490	6.548	1012.3	.13710	94.40	4557.27	220.65	6984.35
94.600	37000.0	99000.0	16125.6	10.702	8.781	1428.6	.18302	94.60	5972.15	218.95	9609.64
94.800	37000.0	99000.0	14264.3	15.903	11.980	2058.4	.24934	94.80	7918.30	217.95	13704.80
95.000	37000.0	99000.0	12180.2	22.803	16.424	2810.0	.32402	95.00	10752.47	217.31	20488.89
95.200	37000.0	99000.0	10059.2	33.086	22.127	3694.8	.43636	95.20	14707.69	219.20	30845.35
95.400	37000.0	99000.0	7835.7	44.474	29.232	4053.0	.43801	95.40	19903.91	226.75	46458.49
									27092.71	237.13	64556.93

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
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THE APPARENT AND ASTRONOMICAL ANGLES ARE  
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THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	TIEFF (11)	P (TAN) (12)
81.000	38000.0	99000.0	38000.0	.025	.026	.0	.00046	81.00	215.88	259.60	407.34
82.000	38000.0	99000.0	38000.0	.027	.028	.0	.00051	82.00	216.89	259.54	407.34
83.000	38000.0	99000.0	38000.0	.031	.032	.0	.00058	83.00	218.26	259.45	407.34
84.000	38000.0	99000.0	38000.0	.035	.037	.0	.00066	84.00	220.16	259.32	407.34
85.000	38000.0	99000.0	38000.0	.041	.042	.0	.00078	85.00	222.91	259.13	407.34
86.000	38000.0	99000.0	38000.0	.049	.051	.0	.00093	86.00	227.01	258.84	407.34
87.000	38000.0	99000.0	38000.0	.060	.062	.0	.00114	87.00	233.41	258.34	407.34
88.000	38000.0	99000.0	38000.0	.077	.079	.0	.00146	88.00	243.95	257.48	407.34
89.200	38000.0	99000.0	38000.0	.111	.114	.0	.00212	89.20	273.59	255.45	407.34
89.400	38000.0	99000.0	38000.0	.119	.122	.0	.00228	89.40	273.54	254.95	407.34
89.600	38000.0	99000.0	38000.0	.128	.131	.0	.00246	89.60	280.32	254.39	407.34
89.800	38000.0	99000.0	38000.0	.139	.142	.0	.00265	89.80	288.07	253.78	407.34
90.000	38000.0	99000.0	38000.0	.141	.154	.0	.00287	90.00	296.82	253.12	394.47
90.200	38000.0	99000.0	37960.9	.154	.168	1.2	.00312	90.20	307.52	252.42	396.69
90.400	38000.0	99000.0	37843.7	.169	.184	2.5	.00341	90.40	318.48	251.72	403.30
90.600	38000.0	99000.0	37646.3	.187	.202	3.9	.00373	90.60	332.11	251.01	414.69
90.800	38000.0	99000.0	37374.8	.207	.223	5.6	.00411	90.80	348.79	250.33	431.09
91.000	38000.0	99000.0	37023.1	.231	.247	7.6	.00455	91.00	366.94	249.69	453.26
91.200	38000.0	99000.0	36593.3	.258	.276	10.0	.00507	91.21	392.52	249.08	481.61
91.400	38000.0	99000.0	36085.2	.291	.309	12.9	.00567	91.41	421.10	248.53	517.58
91.600	38000.0	99000.0	35499.0	.329	.349	16.4	.00639	91.61	458.72	248.03	562.61
91.800	38000.0	99000.0	34834.0	.388	.398	27.7	.00937	91.81	497.78	246.03	618.46
92.000	38000.0	99000.0	34090.9	.446	.463	29.6	.00936	92.01	551.73	242.03	690.33
92.200	38000.0	99000.0	33269.6	.517	.538	36.6	.01060	92.21	614.51	240.19	779.96
92.400	38000.0	99000.0	32369.8	.605	.629	46.0	.01224	92.41	697.70	238.86	892.02
92.600	38000.0	99000.0	31391.5	.715	.740	58.3	.01432	92.61	797.93	237.84	1032.32
92.800	38000.0	99000.0	30334.4	.851	.878	74.4	.01692	92.82	920.10	237.03	1209.12
93.000	38000.0	99000.0	29196.8	1.055	1.069	107.6	.02253	93.02	1089.69	232.31	1443.07
93.200	38000.0	99000.0	27981.0	1.292	1.308	136.1	.02672	93.23	1302.46	229.86	1747.61
93.400	38000.0	99000.0	26685.3	1.602	1.612	177.4	.03261	93.43	1571.98	228.29	2146.34
93.600	38000.0	99000.0	25309.2	2.012	2.005	234.0	.04037	93.64	1914.93	227.17	2675.47
93.800	38000.0	99000.0	23851.1	2.582	2.527	323.2	.05220	93.85	2386.16	225.78	3397.04
94.000	38000.0	99000.0	22309.5	3.382	3.236	439.7	.06698	94.07	3009.13	223.80	4398.35
94.200	38000.0	99000.0	20682.5	4.517	4.207	615.0	.0827	94.29	3888.15	221.83	5839.79
94.400	38000.0	99000.0	18967.4	6.210	5.500	861.0	.11678	94.52	5084.44	220.06	7969.82
94.600	38000.0	99000.0	17159.1	8.767	7.440	1208.0	.15331	94.76	6736.17	218.48	11228.46
94.800	38000.0	99000.0	15251.6	12.916	10.120	1731.2	.21073	95.01	9018.77	217.65	16519.52
95.000	38000.0	99000.0	13233.0	19.108	14.031	2535.3	.29194	95.29	12540.87	217.09	25469.82
95.200	38000.0	99000.0	11125.5	27.423	19.688	3264.7	.3628	95.56	17151.07	222.77	38060.50
95.400	38000.0	99000.0	8910.3	38.796	25.577	3863.4	.41427	95.81	23490.89	231.91	55084.81
95.600	38000.0	99000.0	6579.3	59.322	34.423	5348.2	.54199	96.14	32076.86	243.91	87767.54

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
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APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF) (10)	TIEFF) (11)	PITAN) (12)
81.000	39000.0	99000.0	39000.0	.021	.022	.0	.00040	81.00	189.36	261.86	354.33
82.000	39000.0	99000.0	39000.0	.024	.025	.0	.00045	82.00	190.25	261.81	354.33
83.000	39000.0	99000.0	39000.0	.027	.028	.0	.00051	83.00	191.46	261.74	354.33
84.000	39000.0	99000.0	39000.0	.031	.032	.0	.00058	84.00	193.15	261.64	354.33
85.000	39000.0	99000.0	39000.0	.036	.037	.0	.00068	85.00	195.58	261.49	354.33
86.000	39000.0	99000.0	39000.0	.043	.044	.0	.00081	86.00	199.21	261.24	354.33
87.000	39000.0	99000.0	39000.0	.052	.054	.0	.00100	87.00	204.89	260.82	354.33
88.000	39000.0	99000.0	39000.0	.067	.069	.0	.00128	88.00	214.20	260.07	354.33
89.200	39000.0	99000.0	39000.0	.097	.099	.0	.00188	89.20	234.94	258.15	354.33
89.400	39000.0	99000.0	39000.0	.104	.106	.0	.00202	89.40	240.11	257.61	354.33
89.600	39000.0	99000.0	39000.0	.112	.114	.0	.00218	89.60	245.98	256.99	354.33
89.800	39000.0	99000.0	39000.0	.121	.123	.0	.00236	89.80	252.64	256.25	354.33
90.000	39000.0	99000.0	39000.0	.122	.134	.0	.00255	90.00	260.15	255.42	342.55
90.200	39000.0	99000.0	38960.9	.134	.146	1.0	.00277	90.20	269.32	254.51	344.47
90.400	39000.0	99000.0	38843.7	.147	.160	2.2	.00301	90.40	278.68	253.56	350.21
90.600	39000.0	99000.0	38648.3	.162	.175	3.5	.00329	90.60	290.35	252.61	360.09
90.800	39000.0	99000.0	38374.8	.180	.194	4.9	.00361	90.80	304.68	251.69	374.33
91.000	39000.0	99000.0	38023.1	.200	.215	6.7	.00398	91.00	320.29	250.83	393.57
91.200	39000.0	99000.0	37593.3	.224	.240	8.7	.00443	91.20	342.38	250.04	418.17
91.400	39000.0	99000.0	37085.3	.252	.269	11.2	.00495	91.40	367.10	249.32	449.39
91.600	39000.0	99000.0	36499.0	.286	.304	14.3	.00557	91.60	399.70	248.68	488.46
91.800	39000.0	99000.0	35834.6	.325	.345	18.0	.00632	91.80	433.03	248.12	536.59
92.000	39000.0	99000.0	35091.8	.373	.394	22.7	.00721	92.00	476.96	247.62	596.22
92.200	39000.0	99000.0	34270.1	.446	.462	32.8	.00943	92.20	531.66	242.66	672.55
92.400	39000.0	99000.0	33372.5	.521	.542	40.2	.01067	92.40	603.70	240.49	768.67
92.600	39000.0	99000.0	32392.4	.615	.638	50.6	.01242	92.60	690.29	239.01	889.35
92.800	39000.0	99000.0	31335.7	.733	.758	64.4	.01465	92.80	795.78	237.90	1041.69
93.000	39000.0	99000.0	30200.1	.880	.907	82.6	.01747	93.00	935.42	237.04	1234.53
93.200	39000.0	99000.0	28983.9	1.104	1.119	119.1	.02330	93.20	1119.06	231.87	1493.83
93.400	39000.0	99000.0	27689.2	1.367	1.381	152.9	.02810	93.40	1350.47	229.55	1832.41
93.600	39000.0	99000.0	26314.4	1.714	1.719	201.0	.03470	93.60	1644.56	228.04	2280.88
93.800	39000.0	99000.0	24858.6	2.187	2.162	274.0	.04434	93.80	2046.23	226.86	2885.45
94.000	39000.0	99000.0	23320.3	2.834	2.758	368.0	.05624	94.00	2574.88	225.26	3713.75
94.200	39000.0	99000.0	21697.1	3.784	3.580	520.8	.07490	94.20	3320.90	223.05	4904.72
94.400	39000.0	99000.0	19487.9	5.152	4.711	722.2	.09831	94.40	4333.41	221.22	6629.23
94.600	39000.0	99000.0	18186.9	7.231	6.309	1026.2	.13226	94.60	5734.06	219.19	9263.75
94.800	39000.0	99000.0	16290.8	10.488	8.564	1460.4	.17849	94.80	7669.45	218.07	13416.24
95.000	39000.0	99000.0	14289.2	15.773	11.830	2126.0	.24618	95.00	10513.01	217.37	20434.23
95.200	39000.0	99000.0	12182.4	23.217	16.431	2935.8	.32413	95.20	14692.81	219.22	31388.35
95.400	39000.0	99000.0	9977.4	33.246	22.302	3647.3	.38876	95.40	20298.13	226.95	46667.42
95.600	39000.0	99000.0	7671.5	48.449	29.960	4584.5	.46953	95.60	27819.63	238.48	70304.14

UNREFRACTED RAY STRIKES OISC



ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	UPPER HEIGHT (2)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (IAN) (12)
81.000	40000.0	99000.0	.019	.019	.0	.00033	81.00	166.66	264.45	308.21
82.000	40000.0	99000.0	.021	.022	.0	.00037	82.00	167.45	264.42	308.21
83.000	40000.0	99000.0	.023	.024	.0	.00042	83.00	168.54	264.39	308.21
84.000	40000.0	99000.0	.027	.028	.0	.00048	84.00	170.04	264.33	308.21
85.000	40000.0	99000.0	.031	.032	.0	.00056	85.00	172.22	264.23	308.21
86.000	40000.0	99000.0	.037	.038	.0	.00066	86.00	175.47	264.07	308.21
87.000	40000.0	99000.0	.046	.047	.0	.00081	87.00	180.55	263.80	308.21
88.000	40000.0	99000.0	.058	.058	.0	.00104	88.00	188.92	263.32	308.21
89.000	40000.0	99000.0	.084	.085	.0	.00148	89.00	207.56	262.29	308.21
89.400	40000.0	99000.0	.090	.091	.0	.00159	89.40	212.15	262.06	308.21
89.600	40000.0	99000.0	.097	.098	.0	.00171	89.60	217.29	261.82	308.21
89.800	40000.0	99000.0	.105	.106	.0	.00184	89.80	222.98	261.57	308.21
90.000	40000.0	99000.0	.098	.105	.0	.00199	90.00	229.17	261.30	298.25
90.200	40000.0	99000.0	.108	.125	1.0	.00268	90.20	236.62	259.90	299.84
90.400	40000.0	99000.0	.120	.137	2.4	.00346	90.40	244.46	257.77	304.59
90.600	40000.0	99000.0	.141	.151	3.4	.00344	90.60	254.51	255.30	312.70
90.800	40000.0	99000.0	.156	.168	4.5	.00348	90.80	266.74	253.79	325.05
91.000	40000.0	99000.0	.174	.187	5.9	.00370	91.00	280.06	252.49	341.60
91.200	40000.0	99000.0	.194	.209	7.7	.00404	91.20	299.05	251.36	363.10
91.400	40000.0	99000.0	.219	.234	9.8	.00446	91.40	320.36	250.39	390.20
91.600	40000.0	99000.0	.248	.264	12.5	.00498	91.60	348.55	249.54	424.12
91.800	40000.0	99000.0	.282	.300	15.7	.00561	91.81	377.40	248.81	465.88
92.000	40000.0	99000.0	.324	.343	19.8	.00637	92.01	400.31	247.64	517.62
92.200	40000.0	99000.0	.374	.395	24.9	.00730	92.21	427.00	246.18	581.72
92.400	40000.0	99000.0	.449	.466	36.3	.00963	92.41	522.31	243.05	662.83
92.600	40000.0	99000.0	.530	.550	44.2	.01090	92.61	597.32	240.62	766.63
92.800	40000.0	99000.0	.631	.654	55.9	.01277	92.81	688.46	239.03	897.69
93.000	40000.0	99000.0	.758	.784	71.5	.01519	93.02	809.04	237.87	1063.46
93.200	40000.0	99000.0	.921	.947	99.1	.01937	93.22	959.19	236.95	1277.08
93.400	40000.0	99000.0	1.167	1.182	132.9	.02443	93.42	1160.36	231.32	1565.67
93.600	40000.0	99000.0	1.462	1.473	173.0	.02992	93.63	1412.75	229.16	1945.66
93.800	40000.0	99000.0	1.856	1.852	229.6	.03737	93.84	1756.79	227.72	2455.21
94.000	40000.0	99000.0	2.398	2.358	312.3	.04786	94.05	2207.05	226.35	3149.89
94.200	40000.0	99000.0	3.183	3.049	446.8	.06429	94.26	2839.20	224.38	4136.49
94.400	40000.0	99000.0	4.297	4.005	605.8	.08280	94.48	3654.89	222.40	5543.35
94.600	40000.0	99000.0	5.987	5.349	823.4	.11167	94.71	4882.83	220.33	7670.62
94.800	40000.0	99000.0	8.588	7.258	1235.9	.15158	94.95	6526.76	218.62	10987.27
95.000	40000.0	99000.0	12.873	9.996	1789.0	.20816	95.21	8931.46	217.71	16451.55
95.200	40000.0	99000.0	19.432	14.039	2649.0	.29209	95.49	12528.39	217.12	25887.56
95.400	40000.0	99000.0	28.491	19.339	3463.1	.36618	95.77	17288.04	222.95	39527.14
95.600	40000.0	99000.0	38.871	25.982	3801.9	.39572	96.00	23803.28	233.21	55794.58
95.800	40000.0	99000.0	65.225	35.695	5953.3	.57632	96.38	33206.34	245.04	97145.09

UNREFRACTED RAY STRIKES DISC



## REFRACTON AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMIC ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFFF (10)	TIEFFF (11)	PITAN) (12)
81.000	41000.0	99000.0	41000.0	.016	.017	.0	.00029	81.00	145.94	265.40	270.56
82.000	41000.0	99000.0	41000.0	.018	.019	.0	.00032	82.00	146.64	265.37	270.56
83.000	41000.0	99000.0	41000.0	.020	.021	.0	.00037	83.00	147.59	265.34	270.56
84.000	41000.0	99000.0	41000.0	.023	.024	.0	.00042	84.00	148.91	265.29	270.56
85.000	41000.0	99000.0	41000.0	.027	.028	.0	.00049	85.00	150.82	265.21	270.56
86.000	41000.0	99000.0	41000.0	.032	.034	.0	.00058	86.00	153.68	265.06	270.56
87.000	41000.0	99000.0	41000.0	.040	.041	.0	.00071	87.00	158.14	264.80	270.56
88.000	41000.0	99000.0	41000.0	.050	.052	.0	.00091	88.00	165.49	264.31	270.56
89.000	41000.0	99000.0	41000.0	.072	.075	.0	.00130	89.00	181.86	263.18	270.56
89.400	41000.0	99000.0	41000.0	.078	.080	.0	.00140	89.40	185.88	262.91	270.56
89.600	41000.0	99000.0	41000.0	.083	.086	.0	.00150	89.60	190.39	262.63	270.56
89.800	41000.0	99000.0	41000.0	.090	.093	.0	.00162	89.80	195.38	262.32	270.56
90.000	41000.0	99000.0	41000.0	.090	.101	.0	.00175	90.00	200.80	262.00	260.82
90.200	41000.0	99000.0	40960.9	.099	.109	.7	.00190	90.20	209.42	261.67	262.20
90.400	41000.0	99000.0	40843.7	.108	.119	1.5	.00207	90.40	217.78	261.34	266.33
90.600	41000.0	99000.0	40648.3	.119	.130	2.4	.00227	90.60	225.79	261.02	273.80
90.800	41000.0	99000.0	40374.8	.132	.144	3.4	.00249	90.80	233.32	260.70	283.93
91.000	41000.0	99000.0	40023.2	.146	.159	4.6	.00275	91.00	240.31	260.39	297.52
91.200	41000.0	99000.0	39593.0	.171	.179	7.5	.00383	91.20	263.39	255.35	315.29
91.400	41000.0	99000.0	39084.9	.192	.202	8.9	.00399	91.40	281.27	253.18	338.79
91.600	41000.0	99000.0	38498.7	.217	.229	11.0	.00439	91.60	305.31	251.63	368.23
91.800	41000.0	99000.0	37834.3	.247	.260	13.8	.00491	91.80	330.02	250.41	404.47
92.000	41000.0	99000.0	37091.6	.282	.298	17.3	.00557	92.00	362.87	248.62	449.37
92.200	41000.0	99000.0	36270.7	.326	.343	21.7	.00637	92.20	401.62	247.95	504.99
92.400	41000.0	99000.0	35371.5	.379	.398	27.4	.00735	92.40	452.86	247.95	573.57
92.600	41000.0	99000.0	34393.2	.458	.473	40.0	.00977	92.60	517.20	243.41	661.01
92.800	41000.0	99000.0	33337.0	.544	.564	48.8	.01113	92.80	596.10	240.77	773.71
93.000	41000.0	99000.0	32272.1	.654	.676	62.0	.01317	93.00	700.22	239.09	916.27
93.200	41000.0	99000.0	30988.5	.793	.817	79.8	.01581	93.20	829.74	237.87	1098.72
93.400	41000.0	99000.0	29694.4	1.000	1.006	127.1	.02294	93.40	996.30	234.42	1340.66
93.600	41000.0	99000.0	28321.7	1.248	1.261	149.7	.02587	93.60	1214.04	230.75	1661.45
93.800	41000.0	99000.0	26888.2	1.582	1.588	197.4	.03214	93.80	1509.11	228.76	2092.83
94.000	41000.0	99000.0	25335.1	2.034	2.018	264.6	.04063	94.00	1893.75	227.42	2677.37
94.200	41000.0	99000.0	23718.7	2.676	2.602	371.0	.05363	94.20	2430.74	225.74	3493.53
94.400	41000.0	99000.0	22177.9	3.602	3.410	513.3	.07029	94.40	3123.62	223.66	4657.44
94.600	41000.0	99000.0	20229.8	4.972	4.542	728.1	.09442	94.60	4163.12	221.49	6385.82
94.800	41000.0	99000.0	18350.0	7.083	6.155	1051.5	.12924	94.80	5557.43	219.38	9062.10
95.000	41000.0	99000.0	16374.1	10.441	8.460	1509.8	.17634	95.00	7593.81	218.15	13344.42
95.200	41000.0	99000.0	14291.1	16.312	11.836	2221.9	.24632	95.20	10502.80	217.39	20732.18
95.400	41000.0	99000.0	12099.9	24.096	16.654	3112.9	.32933	95.40	14817.34	219.33	32563.38
95.600	41000.0	99000.0	9819.9	32.929	22.609	3414.7	.35607	95.60	20568.56	228.08	46210.88
95.800	41000.0	99000.0	7411.3	53.446	31.104	5224.7	.50913	95.80	28826.83	239.68	78368.25

UNREFRACTED RAY STRIKES DISC



ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
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 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M(N) HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	42000.0	99000.0	42000.0	.014	.015	.0	.00025	81.00	127.78	266.48	237.02
82.000	42000.0	99000.0	42000.0	.016	.017	.0	.00028	82.00	128.39	266.47	237.02
83.000	42000.0	99000.0	42000.0	.018	.019	.0	.00032	83.00	129.23	266.45	237.02
84.000	42000.0	99000.0	42000.0	.020	.021	.0	.00037	84.00	130.39	266.41	237.02
85.000	42000.0	99000.0	42000.0	.024	.025	.0	.00043	85.00	132.07	266.35	237.02
86.000	42000.0	99000.0	42000.0	.028	.029	.0	.00051	86.00	134.57	266.22	237.02
87.000	42000.0	99000.0	42000.0	.035	.036	.0	.00063	87.00	138.49	265.99	237.02
88.000	42000.0	99000.0	42000.0	.044	.046	.0	.00080	88.00	144.95	265.52	237.02
89.200	42000.0	99000.0	42000.0	.063	.065	.0	.00115	89.20	159.31	264.30	237.02
89.400	42000.0	99000.0	42000.0	.068	.070	.0	.00123	89.40	162.85	264.00	237.02
89.600	42000.0	99000.0	42000.0	.073	.075	.0	.00132	89.60	166.80	263.66	237.02
89.800	42000.0	99000.0	42000.0	.079	.081	.0	.00143	89.80	171.18	263.30	237.02
90.000	42000.0	99000.0	42000.0	.079	.088	.0	.00154	90.00	175.94	262.91	228.08
90.200	42000.0	99000.0	41960.9	.086	.096	.6	.00167	90.20	183.49	262.50	229.28
90.400	42000.0	99000.0	41843.7	.095	.104	1.3	.00182	90.40	190.83	262.09	232.89
90.600	42000.0	99000.0	41648.3	.104	.114	2.1	.00199	90.60	197.84	261.68	239.43
90.800	42000.0	99000.0	41374.8	.115	.126	3.0	.00219	90.80	204.94	261.28	248.29
91.000	42000.0	99000.0	41023.1	.128	.139	4.0	.00242	91.00	210.55	260.90	260.16
91.200	42000.0	99000.0	40593.3	.143	.155	5.3	.00268	91.20	226.67	260.54	275.91
91.400	42000.0	99000.0	40085.3	.160	.173	6.8	.00299	91.40	232.73	260.20	295.16
91.600	42000.0	99000.0	39496.7	.188	.197	10.4	.00406	91.60	268.64	255.07	319.73
91.800	42000.0	99000.0	38834.3	.214	.226	12.3	.00435	91.80	289.40	252.73	351.16
92.000	42000.0	99000.0	38091.0	.245	.259	15.2	.00488	92.00	317.49	251.13	390.13
92.200	42000.0	99000.0	37270.7	.283	.298	19.0	.00556	92.20	350.84	249.90	438.39
92.400	42000.0	99000.0	36371.6	.328	.346	23.9	.00641	92.40	395.16	248.94	497.89
92.600	42000.0	99000.0	35394.1	.385	.404	30.1	.00746	92.60	448.45	248.16	571.99
92.800	42000.0	99000.0	34337.4	.469	.484	43.9	.00993	92.80	516.13	243.43	667.05
93.000	42000.0	99000.0	33202.8	.563	.583	54.1	.01147	93.00	606.23	240.73	789.62
93.200	42000.0	99000.0	31985.5	.683	.705	69.2	.01370	93.20	718.05	239.01	946.49
93.400	42000.0	99000.0	30697.2	.836	.861	89.6	.01662	93.40	858.83	237.77	1148.49
93.600	42000.0	99000.0	29324.3	1.067	1.077	132.8	.02283	93.62	1043.02	233.17	1420.24
93.800	42000.0	99000.0	27872.5	1.350	1.360	170.3	.02772	93.83	1296.64	230.13	1786.04
94.000	42000.0	99000.0	26340.3	1.732	1.730	227.3	.03492	94.03	1626.45	228.32	2281.02
94.200	42000.0	99000.0	24726.4	2.263	2.225	315.1	.04562	94.25	2083.99	226.84	2963.09
94.400	42000.0	99000.0	23029.4	3.027	2.904	430.2	.05908	94.46	2671.63	225.20	3924.40
94.600	42000.0	99000.0	21245.7	4.151	3.863	615.5	.08060	94.68	3553.62	222.70	5344.23
94.800	42000.0	99000.0	19373.1	5.861	5.220	885.1	.10912	94.91	4734.21	220.53	7499.80
95.000	42000.0	99000.0	17406.2	8.541	7.170	1278.1	.14974	95.15	6461.12	218.72	10916.41
95.200	42000.0	99000.0	15337.6	13.045	10.001	1869.9	.20823	95.41	8922.37	217.74	16660.71
95.400	42000.0	99000.0	13153.3	20.115	14.234	2801.5	.29611	95.70	12640.54	217.12	26786.58
95.600	42000.0	99000.0	10881.5	28.217	19.642	3228.3	.33420	95.93	17723.48	223.62	39136.98
95.800	42000.0	99000.0	8493.6	44.230	27.099	4661.1	.45587	96.26	24964.34	234.42	64164.88

UNREFRACTED RAY STRIKES D15C



## REFRACTON, AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M(N). HEIGHT (4)	CHAPMAN AIR MASS (5)	OPT(CAL) AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	43000.0	99000.0	43000.0	.013	.C13	.0	.00022	81.00	111.86	267.72	207.63
82.000	43000.0	99000.0	43000.0	.014	.015	.0	.00025	82.00	112.39	267.72	207.63
83.000	43000.0	99000.0	43000.0	.016	.016	.0	.00028	83.00	113.13	267.72	207.63
84.000	43000.0	99000.0	43000.0	.018	.019	.0	.00032	84.00	114.14	267.70	207.63
85.000	43000.0	99000.0	43000.0	.021	.022	.0	.00038	85.00	115.61	267.67	207.63
86.000	43000.0	99000.0	43000.0	.025	.026	.0	.00045	86.00	117.81	267.59	207.63
87.000	43000.0	99000.0	43000.0	.030	.032	.0	.00055	87.00	121.25	267.41	207.63
88.000	43000.0	99000.0	43000.0	.039	.040	.0	.00070	88.00	126.91	267.00	207.63
89.000	43000.0	99000.0	43000.0	.055	.057	.0	.00102	89.00	139.51	265.78	207.63
89.400	43000.0	99000.0	43000.0	.064	.066	.0	.00117	89.40	142.62	265.44	207.63
89.800	43000.0	99000.0	43000.0	.069	.071	.0	.00126	89.80	146.09	265.05	207.63
90.000	43000.0	99000.0	43000.0	.075	.077	.0	.00137	90.00	149.94	264.61	207.63
90.200	43000.0	99000.0	42960.9	.083	.084	.6	.00148	90.20	154.12	264.13	199.44
90.400	43000.0	99000.0	42843.7	.091	.091	1.2	.00161	90.40	160.76	263.62	200.49
90.600	43000.0	99000.0	42648.3	.091	.100	1.9	.00176	90.60	167.19	263.09	203.65
90.800	43000.0	99000.0	42374.7	.101	.110	2.6	.00193	90.80	173.34	262.56	209.37
91.000	43000.0	99000.0	42023.0	.112	.122	3.5	.00213	91.00	179.12	262.04	217.12
91.200	43000.0	99000.0	41593.2	.125	.136	4.6	.00236	91.20	184.48	261.55	227.49
91.400	43000.0	99000.0	41085.1	.140	.151	5.9	.00263	91.40	158.61	261.09	241.27
91.600	43000.0	99000.0	40498.9	.158	.170	7.5	.00295	91.60	203.90	260.67	258.10
91.800	43000.0	99000.0	39834.3	.179	.193	13.2	.00447	91.80	228.54	260.29	279.46
92.000	43000.0	99000.0	39091.5	.212	.224	13.7	.00436	92.00	255.18	258.17	305.40
92.200	43000.0	99000.0	38270.6	.245	.259	16.7	.00489	92.20	278.67	253.67	338.71
92.400	43000.0	99000.0	37371.5	.285	.301	20.9	.00560	92.40	307.08	251.67	380.59
92.600	43000.0	99000.0	36394.0	.334	.352	26.3	.00651	92.60	345.24	250.23	432.21
92.800	43000.0	99000.0	35338.2	.394	.414	33.3	.00763	92.80	391.30	249.14	496.50
93.000	43000.0	99000.0	34203.2	.485	.501	48.2	.01016	93.00	447.36	248.28	576.72
93.200	43000.0	99000.0	32990.1	.588	.609	60.2	.01192	93.20	524.91	243.19	680.68
93.400	43000.0	99000.0	31698.3	.720	.743	77.6	.01440	93.40	621.59	240.53	815.56
93.600	43000.0	99000.0	30327.4	.891	.916	101.3	.01764	93.60	743.13	238.82	989.18
93.800	43000.0	99000.0	28875.4	1.152	1.163	148.5	.02412	93.80	896.54	237.60	1215.13
94.000	43000.0	99000.0	27344.5	1.476	1.483	195.7	.03007	94.00	1114.14	232.09	1525.57
94.200	43000.0	99000.0	25732.5	1.919	1.906	264.0	.03839	94.20	1397.22	229.49	1944.63
94.400	43000.0	99000.0	24038.1	2.450	2.481	365.1	.05022	94.40	1788.64	227.86	2518.21
94.600	43000.0	99000.0	22258.6	3.479	3.290	522.3	.06799	94.60	2289.36	226.31	3321.02
94.800	43000.0	99000.0	20391.8	4.867	4.434	746.9	.09231	94.80	3001.81	223.98	4490.86
95.000	43000.0	99000.0	18432.6	7.039	6.031	1088.6	.12779	95.00	4037.81	221.71	6243.46
95.200	43000.0	99000.0	16376.1	10.559	8.465	1578.4	.17641	95.20	5500.62	219.51	8997.21
95.400	43000.0	99000.0	14210.2	16.289	11.999	2349.7	.24967	95.40	7585.94	218.18	13485.83
95.600	43000.0	99000.0	11937.0	23.879	16.972	2968.0	.30637	95.60	10719.07	217.39	21412.48
95.800	43000.0	99000.0	9570.2	36.598	23.499	4064.1	.39988	95.80	15211.15	217.68	32660.98
96.000	43000.0	99000.0	7062.0	59.455	32.633	5846.8	.54541	96.00	21343.41	229.62	51936.06
									30110.58	240.99	87931.55



# REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF (10)	TIEFF (11)	PITAN) (12)
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UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/50 M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF) (10)	TIEFF) (11)	PITAN) (12)
81.000	44000.0	99000.0	44000.0	.011	.011	.0	.00020	81.00	97.89	269.15	181.89
82.000	44000.0	99000.0	44000.0	.012	.013	.0	.00022	82.00	98.36	269.16	181.89
83.000	44000.0	99000.0	44000.0	.014	.014	.0	.00025	83.00	99.00	269.18	181.89
84.000	44000.0	99000.0	44000.0	.016	.016	.0	.00028	84.00	99.89	269.20	181.89
85.000	44000.0	99000.0	44000.0	.018	.019	.0	.00033	85.00	101.18	269.21	181.89
86.000	44000.0	99000.0	44000.0	.022	.023	.0	.00039	86.00	103.10	269.19	181.89
87.000	44000.0	99000.0	44000.0	.027	.028	.0	.00048	87.00	106.11	269.11	181.89
88.000	44000.0	99000.0	44000.0	.034	.035	.0	.00062	88.00	111.05	268.85	181.89
89.200	44000.0	99000.0	44000.0	.049	.050	.0	.00091	89.20	122.04	267.83	181.89
89.400	44000.0	99000.0	44000.0	.052	.054	.0	.00098	89.40	124.75	267.49	181.89
89.600	44000.0	99000.0	44000.0	.056	.058	.0	.00107	89.60	127.79	267.07	181.89
89.800	44000.0	99000.0	44000.0	.060	.062	.0	.00117	89.80	131.16	266.56	181.89
90.000	44000.0	99000.0	44000.0	.066	.067	.0	.00129	90.00	134.85	265.95	174.39
90.200	44000.0	99000.0	43960.9	.066	.073	.5	.00136	90.20	140.72	265.26	175.31
90.400	44000.0	99000.0	43843.7	.072	.080	1.1	.00145	90.40	146.41	264.54	178.07
90.600	44000.0	99000.0	43648.3	.080	.088	1.7	.00157	90.60	151.83	263.80	183.08
90.800	44000.0	99000.0	43374.7	.088	.096	2.3	.00171	90.80	156.91	263.10	189.85
91.000	44000.0	99000.0	43023.0	.098	.107	3.1	.00188	91.00	161.62	262.43	198.92
91.200	44000.0	99000.0	42593.0	.109	.119	4.1	.00208	91.20	174.01	261.83	210.97
91.400	44000.0	99000.0	42185.0	.122	.133	5.2	.00231	91.40	178.65	261.28	225.69
91.600	44000.0	99000.0	41498.7	.138	.149	6.6	.00259	91.60	200.24	260.79	244.37
91.800	44000.0	99000.0	40834.3	.156	.168	8.3	.00292	91.80	223.33	260.36	266.90
92.000	44000.0	99000.0	40191.7	.178	.192	10.4	.00332	92.00	231.81	259.99	295.05
92.200	44000.0	99000.0	39270.4	.212	.224	15.2	.00440	92.20	269.72	254.39	330.29
92.400	44000.0	99000.0	38371.3	.247	.261	18.4	.00493	92.40	302.23	252.02	375.22
92.600	44000.0	99000.0	37393.9	.290	.306	23.0	.00569	92.60	341.87	250.41	430.99
92.800	44000.0	99000.0	36338.1	.342	.360	29.0	.00666	92.80	390.33	249.22	500.58
93.000	44000.0	99000.0	35233.9	.408	.428	36.9	.00788	93.00	454.29	248.30	588.14
93.200	44000.0	99000.0	33990.5	.506	.524	53.1	.01048	93.20	538.19	242.73	702.94
93.400	44000.0	99000.0	32698.9	.620	.641	67.5	.01251	93.40	643.20	240.21	852.20
93.600	44000.0	99000.0	31328.5	.767	.791	87.7	.01528	93.60	775.64	238.55	1046.35
93.800	44000.0	99000.0	29878.2	.986	.987	142.0	.02258	93.80	955.41	236.60	1306.11
94.000	44000.0	99000.0	28347.5	1.259	1.270	169.3	.02600	94.00	1200.51	231.09	1659.86
94.200	44000.0	99000.0	26737.1	1.634	1.634	227.0	.03302	94.20	1536.17	228.85	2145.64
94.400	44000.0	99000.0	25145.1	2.159	2.123	309.7	.04269	94.40	1963.68	227.39	2818.70
94.600	44000.0	99000.0	23269.4	2.924	2.804	437.5	.05713	94.60	2568.43	225.47	3784.03
94.800	44000.0	99000.0	21471.1	4.062	3.772	631.7	.07824	94.80	3447.73	222.92	5222.74
95.000	44000.0	99000.0	19455.1	5.820	5.158	916.8	.10793	95.00	4685.28	220.66	7440.23
95.200	44000.0	99000.0	17407.9	8.623	7.174	1336.4	.14981	95.20	6454.34	218.75	11014.42
95.400	44000.0	99000.0	15257.2	13.444	10.137	1977.4	.21103	95.40	8941.36	217.74	17163.16
95.600	44000.0	99000.0	12486.0	20.828	14.592	2873.0	.32322	95.60	13005.17	217.12	27728.00
95.800	44000.0	99000.0	10636.1	30.723	20.350	3615.4	.35667	95.80	18377.93	225.14	42604.78
96.000	44000.0	99000.0	8147.7	48.973	28.450	5231.1	.48967	96.00	26112.01	235.64	71796.81



# REFRACTON AIRMASS TABLES

MIDLATITUDE SUMMER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HE(HT (2)	UPPER HEIGHT (3)	MIN. HE(HT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
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UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/500 M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	UPPER HEIGHT (2)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	45000.0	45000.0	.010	.010	.0	.00016	81.00	85.94	270.74	159.34
82.000	45000.0	45000.0	.011	.011	.0	.00018	82.00	86.36	270.78	159.34
83.000	45000.0	45000.0	.012	.013	.0	.00021	83.00	86.92	270.83	159.34
84.000	45000.0	45000.0	.014	.014	.0	.00024	84.00	87.70	270.89	159.34
85.000	45000.0	45000.0	.016	.017	.0	.00027	85.00	88.83	270.96	159.34
86.000	45000.0	45000.0	.019	.020	.0	.00033	86.00	90.52	271.03	159.34
87.000	45000.0	45000.0	.023	.024	.0	.00040	87.00	93.15	271.10	159.34
88.000	45000.0	45000.0	.030	.031	.0	.00051	88.00	97.47	271.13	159.34
89.200	45000.0	45000.0	.043	.044	.0	.00072	89.20	107.05	271.01	159.34
89.400	45000.0	45000.0	.046	.047	.0	.00077	89.40	109.40	270.97	159.34
89.800	45000.0	45000.0	.053	.054	.0	.00083	89.80	112.02	270.92	159.34
90.000	45000.0	45000.0	.059	.059	.0	.00089	90.00	114.92	270.87	159.34
90.200	45000.0	45000.0	.054	.063	.4	.00096	90.20	118.08	270.80	153.23
90.400	45000.0	44960.9	.060	.069	.9	.00110	90.40	123.05	269.83	154.00
90.600	45000.0	44843.6	.070	.076	1.5	.00126	90.60	127.93	268.78	156.31
90.800	45000.0	44648.2	.077	.084	2.5	.00143	90.80	132.69	267.51	160.08
91.000	45000.0	44374.5	.085	.093	3.1	.00164	91.00	137.25	265.89	166.00
91.200	45000.0	43992.8	.095	.104	3.7	.00189	91.20	141.54	263.85	173.94
91.400	45000.0	43684.7	.107	.116	4.6	.00193	91.40	152.34	262.87	184.48
91.600	45000.0	42498.4	.121	.130	5.8	.00211	91.60	156.45	262.11	197.34
91.800	45000.0	41833.9	.136	.148	7.3	.00234	91.80	175.43	261.45	213.68
92.000	45000.0	41491.2	.156	.168	9.1	.00262	92.00	195.70	260.89	233.38
92.200	45000.0	40670.9	.179	.192	11.4	.00296	92.20	203.12	260.41	258.00
92.400	45000.0	39370.9	.214	.225	16.8	.00337	92.40	228.45	260.00	285.19
92.600	45000.0	38393.4	.251	.265	20.2	.00450	92.60	265.61	254.85	325.77
92.800	45000.0	37337.7	.297	.313	25.4	.00503	92.80	299.34	252.18	374.16
93.000	45000.0	36213.6	.354	.372	32.2	.00585	93.00	341.03	250.46	434.53
93.200	45000.0	34991.0	.426	.446	43.9	.00690	93.20	396.37	249.20	510.48
93.400	45000.0	33689.1	.534	.553	59.1	.00867	93.40	465.06	248.23	606.69
93.600	45000.0	32329.0	.660	.683	76.1	.01097	93.60	556.93	242.14	734.41
93.800	45000.0	30879.8	.826	.850	99.9	.01328	93.80	671.30	239.79	901.31
94.000	45000.0	29349.7	1.076	1.084	150.4	.01641	94.00	825.59	238.22	1119.96
94.200	45000.0	27740.5	1.394	1.400	195.7	.02301	94.20	1031.28	233.52	1418.54
94.400	45000.0	26250.2	1.833	1.821	265.9	.02848	94.40	1319.74	230.17	1830.04
94.600	45000.0	24777.4	2.464	2.397	371.3	.03670	94.60	1686.33	228.23	2399.05
94.800	45000.0	22419.2	3.406	3.213	536.9	.04859	94.80	2201.45	226.57	3204.05
95.000	45000.0	20473.3	4.830	4.382	773.9	.06661	95.00	2946.98	224.22	4389.76
95.200	45000.0	18434.1	7.098	6.085	1138.5	.09134	95.20	3995.83	221.83	6188.67
95.400	45000.0	16286.0	10.895	8.580	1669.1	.12768	95.40	5494.93	219.54	9066.33
95.600	45000.0	14445.7	17.118	12.327	2515.1	.17879	95.60	7646.05	218.17	13857.75
95.800	45000.0	11697.0	25.161	17.520	3105.4	.25648	95.80	10910.18	217.37	22495.82
96.000	45000.0	9227.0	40.554	24.689	4613.3	.30843	96.00	15757.83	221.34	34407.00
						.43378	96.43	22552.25	230.83	58184.23



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/CM<sup>2</sup>  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	4500.0	9900.0	6644.7	61.976	34.126	5840.6	.53076	96.73	31844.78	243.60	92284.78

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/50 M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF (10)	T(EFF) (11)	PITAN) (12)
81.000	46000.0	99000.0	46000.0	.008	.009	.0	.00014	81.00	75.72	270.85	140.81
82.000	46000.0	99000.0	46000.0	.009	.010	.0	.00016	82.00	76.09	270.89	140.81
83.000	46000.0	99000.0	46000.0	.011	.011	.0	.00018	83.00	76.58	270.95	140.81
84.000	46000.0	99000.0	46000.0	.012	.013	.0	.00021	84.00	77.27	271.02	140.81
85.000	46000.0	99000.0	46000.0	.014	.015	.0	.00024	85.00	78.26	271.11	140.81
86.000	46000.0	99000.0	46000.0	.017	.018	.0	.00029	86.00	79.75	271.21	140.81
87.000	46000.0	99000.0	46000.0	.020	.021	.0	.00035	87.00	82.07	271.31	140.81
88.000	46000.0	99000.0	46000.0	.026	.027	.0	.00045	88.00	85.88	271.37	140.81
89.200	46000.0	99000.0	46000.0	.037	.039	.0	.00064	89.20	94.33	271.26	140.81
89.400	46000.0	99000.0	46000.0	.040	.041	.0	.00068	89.40	96.40	271.21	140.81
89.600	46000.0	99000.0	46000.0	.043	.044	.0	.00073	89.60	98.71	271.15	140.81
89.800	46000.0	99000.0	46000.0	.046	.048	.0	.00079	89.80	101.27	271.08	140.81
90.000	46000.0	99000.0	46000.0	.045	.052	.0	.00085	90.00	104.05	271.01	134.77
90.200	46000.0	99000.0	45960.9	.049	.056	.3	.00092	90.20	108.39	270.92	135.45
90.400	46000.0	99000.0	45843.6	.054	.061	.7	.00100	90.40	112.61	270.84	137.48
90.600	46000.0	99000.0	45648.2	.060	.067	1.1	.00110	90.60	116.68	270.75	141.18
90.800	46000.0	99000.0	45374.6	.066	.073	1.6	.00120	90.80	120.52	270.67	146.16
91.000	46000.0	99000.0	45022.8	.073	.080	2.2	.00133	91.00	124.10	270.59	152.83
91.200	46000.0	99000.0	44592.8	.084	.089	3.3	.00167	91.20	133.39	268.80	161.30
91.400	46000.0	99000.0	44184.5	.094	.101	4.5	.00200	91.40	137.17	265.00	172.56
91.600	46000.0	99000.0	43496.2	.106	.114	5.2	.00209	91.60	153.63	263.21	186.84
91.800	46000.0	99000.0	42833.6	.120	.129	6.4	.00231	91.80	171.48	262.23	204.06
92.000	46000.0	99000.0	42090.9	.137	.147	8.0	.00260	92.00	177.99	261.45	225.59
92.200	46000.0	99000.0	41270.8	.157	.168	10.0	.00296	92.20	200.21	260.82	251.99
92.400	46000.0	99000.0	40370.8	.182	.194	12.5	.00339	92.40	225.67	260.30	284.43
92.600	46000.0	99000.0	39393.1	.218	.229	18.6	.00457	92.60	263.10	255.23	324.84
92.800	46000.0	99000.0	38337.3	.258	.272	22.3	.00514	92.80	298.59	252.34	377.20
93.000	46000.0	99000.0	37203.5	.307	.323	28.1	.00603	93.00	346.28	250.51	443.10
93.200	46000.0	99000.0	35990.8	.370	.388	35.8	.00717	93.20	405.70	249.20	526.33
93.400	46000.0	99000.0	34699.2	.461	.473	57.7	.01047	93.40	481.88	245.51	633.51
93.600	46000.0	99000.0	33329.3	.569	.589	66.4	.01158	93.60	581.21	241.53	776.57
93.800	46000.0	99000.0	31880.5	.712	.734	86.6	.01423	93.80	714.44	239.35	964.47
94.000	46000.0	99000.0	30352.0	.900	.922	114.7	.01778	94.00	886.46	237.88	1213.03
94.200	46000.0	99000.0	28743.2	1.190	1.198	170.1	.02473	94.22	1133.95	232.03	1562.33
94.400	46000.0	99000.0	27054.3	1.562	1.561	228.8	.03159	94.43	1448.55	229.33	2044.20
94.600	46000.0	99000.0	25283.9	2.082	2.052	314.7	.04127	94.64	1868.78	227.66	2719.11
94.800	46000.0	99000.0	23425.0	2.849	2.740	449.3	.05591	94.86	2521.63	225.68	3697.87
95.000	46000.0	99000.0	21468.1	4.129	3.729	654.8	.07744	95.08	3411.72	223.06	5175.52
95.200	46000.0	99000.0	19456.4	5.862	5.162	958.9	.10800	95.31	4680.47	220.70	7488.43
95.400	46000.0	99000.0	17328.1	8.846	7.271	1413.0	.15180	95.55	6506.52	218.73	11292.66
95.600	46000.0	99000.0	15094.0	14.109	10.411	2116.0	.21672	95.82	9266.05	217.70	18005.40
95.800	46000.0	99000.0	12749.4	20.932	15.011	2667.5	.26666	96.07	13459.07	218.38	27861.80
96.000	46000.0	99000.0	10296.1	33.989	21.405	4129.0	.38904	96.39	19240.58	226.19	47676.37



# REFRACTION AIRMASS TABLES

MICLITUDE SUMMER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIR. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF) (10)	TIEFF) (11)	P(TAN) (12)
96.200	46000.0	99300.0	7735.8	49.122	29.641	4844.1	.44682	96.65	27583.30	238.12	72011.37

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	47000.0	99000.0	47000.0	.007	.008	.0	.00013	81.00	66.72	270.97	124.08
82.000	47000.0	99000.0	47000.0	.008	.009	.0	.00014	82.00	67.04	271.02	124.08
83.000	47000.0	99000.0	47000.0	.009	.010	.0	.00016	83.00	67.47	271.09	124.08
84.000	47000.0	99000.0	47000.0	.011	.011	.0	.00018	84.00	68.08	271.18	124.08
85.000	47000.0	99000.0	47000.0	.012	.013	.0	.00021	85.00	68.95	271.29	124.08
86.000	47000.0	99000.0	47000.0	.015	.015	.0	.00025	86.00	70.26	271.42	124.08
87.000	47000.0	99000.0	47000.0	.018	.019	.0	.00031	87.00	72.31	271.56	124.08
88.000	47000.0	99000.0	47000.0	.023	.024	.0	.00040	88.00	75.67	271.67	124.08
89.200	47000.0	99000.0	47000.0	.033	.034	.0	.00056	89.20	83.11	271.59	124.08
89.400	47000.0	99000.0	47000.0	.035	.036	.0	.00060	89.40	84.94	271.53	124.08
89.600	47000.0	99000.0	47000.0	.037	.039	.0	.00065	89.60	86.98	271.46	124.08
89.800	47000.0	99000.0	47000.0	.040	.042	.0	.00070	89.80	89.23	271.38	124.08
90.000	47000.0	99000.0	47000.0	.043	.046	.0	.00075	90.00	91.68	271.28	118.54
90.200	47000.0	99000.0	47000.0	.048	.050	.3	.00082	90.20	95.51	271.18	119.13
90.400	47000.0	99000.0	47000.0	.048	.054	.6	.00089	90.40	99.24	271.07	120.92
90.600	47000.0	99000.0	47000.0	.052	.059	1.0	.00097	90.60	102.82	270.95	124.18
90.800	47000.0	99000.0	47000.0	.058	.064	1.4	.00106	90.80	106.20	270.84	128.56
91.000	47000.0	99000.0	47000.0	.064	.071	1.9	.00117	91.00	109.36	270.73	134.42
91.200	47000.0	99000.0	47000.0	.071	.079	2.5	.00130	91.20	117.42	270.63	142.20
91.400	47000.0	99000.0	47000.0	.080	.087	3.2	.00144	91.40	120.55	270.54	151.66
91.600	47000.0	99000.0	47000.0	.093	.098	4.7	.00185	91.60	134.61	268.31	163.37
91.800	47000.0	99000.0	47000.0	.105	.112	5.9	.00211	91.80	150.16	264.20	178.43
92.000	47000.0	99000.0	47000.0	.119	.128	7.1	.00231	92.00	155.93	262.88	197.25
92.200	47000.0	99000.0	47000.0	.137	.147	8.8	.00261	92.20	175.46	261.89	220.34
92.400	47000.0	99000.0	47000.0	.159	.170	11.0	.00298	92.40	197.79	261.12	248.70
92.600	47000.0	99000.0	47000.0	.185	.197	13.7	.00345	92.60	223.73	260.50	283.64
92.800	47000.0	99000.0	47000.0	.224	.235	20.3	.00464	92.80	262.34	255.25	327.48
93.000	47000.0	99000.0	47000.0	.267	.281	24.7	.00529	93.01	303.06	252.29	384.63
93.200	47000.0	99000.0	47000.0	.321	.337	31.3	.00626	93.21	354.30	250.43	456.84
93.400	47000.0	99000.0	47000.0	.389	.408	40.2	.00753	93.41	418.89	249.10	548.70
93.600	47000.0	99000.0	47000.0	.490	.506	59.6	.01032	93.61	513.18	244.15	669.37
93.800	47000.0	99000.0	47000.0	.613	.633	75.3	.01237	93.81	618.45	240.86	830.81
94.000	47000.0	99000.0	47000.0	.774	.797	99.3	.01540	94.02	766.95	238.88	1044.31
94.200	47000.0	99000.0	47000.0	1.020	1.020	172.2	.02443	94.22	973.15	235.25	1339.52
94.400	47000.0	99000.0	47000.0	1.332	1.337	197.5	.02727	94.43	1244.56	230.80	1743.60
94.600	47000.0	99000.0	47000.0	1.772	1.759	270.4	.03548	94.64	1622.09	228.56	2314.22
94.800	47000.0	99000.0	47000.0	2.407	2.343	381.4	.04755	94.85	2161.30	226.79	3130.78
95.000	47000.0	99000.0	47000.0	3.369	3.177	557.2	.06598	95.07	2882.05	224.38	4347.78
95.200	47000.0	99000.0	47000.0	4.861	4.386	809.5	.09139	95.29	3991.66	221.88	6223.78
95.400	47000.0	99000.0	47000.0	7.266	6.168	1202.7	.12946	95.53	5540.06	219.50	9276.73
95.600	47000.0	99000.0	47000.0	14.350	8.610	1785.6	.18353	95.78	7876.40	218.12	14484.60
95.800	47000.0	99000.0	47000.0	18.339	12.835	2725.6	.26702	96.07	11344.88	217.32	24095.11
96.000	47000.0	99000.0	47000.0	27.980	18.456	3640.7	.34407	96.34	16521.04	222.31	38792.95



## REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	PITAN) (12)
96.200	47000.0	99000.0	8910.2	41.299	25.849	4340.7	-40156	96.60	23669.20	232.70	59249.98

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SC M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF (10)	TIEFF (11)	PITAN) (12)
81.000	48000.0	99000.0	48000.0	.007	.007	.0	.00011	81.00	58.78	271.11	109.34
82.000	48010.0	99005.0	48005.0	.007	.008	.0	.00013	82.00	59.06	271.17	109.34
83.000	48020.0	99010.0	48010.0	.008	.009	.0	.00014	83.00	59.44	271.26	109.34
84.000	48030.0	99015.0	48015.0	.009	.010	.0	.00016	84.00	59.98	271.36	109.34
85.000	48040.0	99020.0	48020.0	.011	.012	.0	.00019	85.00	60.74	271.50	109.34
86.000	48050.0	99025.0	48025.0	.013	.014	.0	.00022	86.00	61.90	271.67	109.34
87.000	48060.0	99030.0	48030.0	.016	.017	.0	.00028	87.00	63.70	271.87	109.34
88.000	48070.0	99035.0	48035.0	.021	.021	.0	.00035	88.00	66.66	272.05	109.34
89.200	48080.0	99040.0	48040.0	.029	.030	.0	.00050	89.20	73.22	272.04	109.34
89.400	48090.0	99045.0	48045.0	.031	.032	.0	.00054	89.40	74.83	271.99	109.34
89.600	48090.0	99045.0	48045.0	.033	.035	.0	.00058	89.60	76.63	271.91	109.34
89.800	48090.0	99045.0	48045.0	.036	.037	.0	.00062	89.80	78.62	271.80	109.34
90.000	48090.0	99045.0	48045.0	.038	.040	.0	.00067	90.00	80.78	271.68	104.25
90.200	48090.0	99045.0	47960.9	.042	.044	.3	.00072	90.20	84.15	271.54	104.77
90.400	48090.0	99045.0	47843.6	.046	.047	.6	.00079	90.40	87.44	271.39	106.35
90.600	48090.0	99045.0	47648.1	.051	.052	.9	.00086	90.60	90.60	271.23	109.01
90.800	48090.0	99045.0	47374.4	.056	.057	1.3	.00094	90.80	93.58	271.08	113.07
91.000	48090.0	99045.0	47022.6	.063	.063	1.7	.00104	91.00	96.36	270.94	118.23
91.200	48090.0	99045.0	46592.5	.070	.069	2.2	.00127	91.20	103.47	270.80	125.07
91.400	48090.0	99045.0	46084.2	.079	.077	2.8	.00142	91.40	106.23	270.68	133.39
91.600	48090.0	99045.0	45497.8	.089	.086	3.6	.00172	91.60	118.48	270.57	143.94
91.800	48090.0	99045.0	44833.1	.104	.097	4.9	.00217	91.80	131.56	270.08	156.59
92.000	48090.0	99045.0	44090.2	.120	.128	7.8	.00232	92.00	136.77	265.53	172.48
92.200	48090.0	99045.0	43269.1	.139	.148	9.7	.00263	92.20	153.71	263.37	192.66
92.400	48090.0	99045.0	42369.8	.161	.173	12.1	.00303	92.40	173.34	262.19	217.46
92.600	48090.0	99045.0	41392.3	.189	.202	15.2	.00353	92.60	196.09	261.31	248.01
92.800	48090.0	99045.0	40336.6	.231	.252	22.2	.00474	92.80	222.78	260.62	285.82
93.000	48090.0	99045.0	39202.2	.278	.293	27.4	.00549	93.00	266.07	254.96	333.92
93.200	48090.0	99045.0	37985.8	.337	.355	35.0	.00657	93.20	309.92	252.07	396.55
93.400	48090.0	99045.0	36699.0	.413	.433	45.3	.00797	93.40	365.67	250.23	476.22
93.600	48090.0	99045.0	35329.6	.528	.545	66.2	.01085	93.60	436.03	248.92	578.60
93.800	48090.0	99045.0	33680.0	.666	.688	86.1	.01337	93.80	535.46	242.58	715.92
94.000	48090.0	99045.0	32353.7	.832	.874	114.8	.01685	94.00	663.76	240.16	899.37
94.200	48090.0	99045.0	30747.3	1.036	1.144	172.9	.02382	94.20	839.06	238.37	1144.33
94.400	48090.0	99045.0	29059.6	1.309	1.508	232.7	.03055	94.40	1069.23	232.93	1488.33
94.600	48090.0	99045.0	27292.3	2.038	2.006	322.9	.04035	94.60	1393.40	229.74	1971.89
94.800	48090.0	99045.0	25443.2	2.824	2.709	465.9	.05535	94.80	1854.35	227.86	2657.16
95.000	48090.0	99045.0	23509.9	4.051	3.732	685.0	.07749	95.00	2467.02	225.81	3661.75
95.200	48090.0	99045.0	21485.1	5.992	5.231	1012.9	.10932	95.20	3408.14	223.11	5199.28
95.400	48090.0	99045.0	19377.1	9.221	7.465	1511.1	.15578	95.40	4719.34	220.65	7649.81
95.600	48090.0	99045.0	17166.8	14.866	10.836	2291.8	.22551	95.60	6700.22	218.66	11768.01
95.800	48090.0	99045.0	14847.8	23.611	15.872	3278.8	.30983	95.80	9632.78	217.63	19230.55
96.000	48090.0	99045.0	12414.4	23.611	15.872	3278.8	.30983	96.00	14143.01	218.99	31887.20



## REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/50 M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	PI(EFF) (10)	T(EFF) (11)	PITAN) (12)
96.200	48000.0	99000.0	9877.9	34.636	22.502	3939.5	.36451	96.56	20450.84	227.61	49138.50
96.400	48000.0	99000.0	7211.5	60.140	31.983	6092.1	.53080	96.93	29659.42	240.47	88929.41

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	49000.0	99000.0	49000.0	.006	.006	.0	.00010	81.00	51.78	271.26	96.35
82.000	49000.0	99000.0	49000.0	.006	.007	.0	.00011	82.00	52.03	271.34	96.35
83.000	49000.0	99000.0	49000.0	.007	.008	.0	.00013	83.00	52.37	271.44	96.35
84.000	49000.0	99000.0	49000.0	.008	.009	.0	.00014	84.00	52.83	271.58	96.35
85.000	49000.0	99000.0	49000.0	.010	.010	.0	.00017	85.00	53.51	271.75	96.35
86.000	49000.0	99000.0	49000.0	.011	.012	.0	.00020	86.00	54.52	271.97	96.35
87.000	49000.0	99000.0	49000.0	.014	.015	.0	.00024	87.00	56.10	272.24	96.35
88.000	49000.0	99000.0	49000.0	.018	.019	.0	.00031	88.00	58.70	272.54	96.35
89.200	49000.0	99000.0	49000.0	.025	.026	.0	.00045	89.20	64.47	272.72	96.35
89.400	49000.0	99000.0	49000.0	.027	.028	.0	.00048	89.40	65.88	272.68	96.35
89.600	49000.0	99000.0	49000.0	.029	.030	.0	.00052	89.60	67.47	272.60	96.35
89.800	49000.0	99000.0	49000.0	.031	.033	.0	.00056	89.80	69.22	272.48	96.35
90.000	49000.0	99000.0	49000.0	.031	.035	.0	.00061	90.00	71.14	272.32	91.69
90.200	49000.0	99000.0	48960.9	.033	.038	.2	.00065	90.20	74.12	272.12	92.15
90.400	49000.0	99000.0	48843.6	.037	.042	.5	.00070	90.40	77.03	271.90	93.53
90.600	49000.0	99000.0	48648.1	.040	.046	.8	.00076	90.60	79.82	271.66	95.87
90.800	49000.0	99000.0	48374.4	.045	.050	1.1	.00083	90.80	82.46	271.44	99.45
91.000	49000.0	99000.0	48022.4	.049	.055	1.5	.00092	91.00	84.91	271.23	103.98
91.200	49000.0	99000.0	47592.3	.055	.061	2.0	.00101	91.20	91.17	271.04	110.01
91.400	49000.0	99000.0	47084.0	.062	.068	2.5	.00113	91.40	93.61	270.87	117.32
91.600	49000.0	99000.0	46497.5	.069	.076	3.1	.00126	91.60	96.40	270.72	126.60
91.800	49000.0	99000.0	45832.3	.078	.086	3.9	.00141	91.80	100.00	270.60	137.72
92.000	49000.0	99000.0	45089.9	.089	.097	4.9	.00160	92.00	103.98	270.49	151.59
92.200	49000.0	99000.0	44268.6	.105	.112	7.3	.00213	92.20	120.23	270.49	168.46
92.400	49000.0	99000.0	43369.3	.121	.130	8.6	.00234	92.40	134.78	266.97	184.46
92.600	49000.0	99000.0	42391.7	.141	.151	10.6	.00267	92.60	151.86	263.70	190.14
92.800	49000.0	99000.0	41335.9	.165	.177	13.3	.00310	92.80	171.86	262.38	216.86
93.000	49000.0	99000.0	40201.8	.196	.209	16.8	.00364	93.00	195.25	261.41	249.91
93.200	49000.0	99000.0	38999.1	.241	.254	24.4	.00486	93.20	222.82	260.67	291.03
93.400	49000.0	99000.0	37698.3	.293	.308	30.7	.00575	93.40	254.46	251.72	344.25
93.600	49000.0	99000.0	36325.0	.359	.377	39.5	.00696	93.60	319.67	249.95	413.36
93.800	49000.0	99000.0	34880.9	.444	.465	64.2	.01028	93.80	380.48	247.88	502.15
94.000	49000.0	99000.0	33353.7	.574	.593	75.1	.01165	94.00	462.74	241.90	774.80
94.200	49000.0	99000.0	31747.8	.733	.755	99.5	.01461	94.20	574.61	239.47	985.20
94.400	49000.0	99000.0	30062.4	.948	.969	134.0	.01865	94.40	725.99	237.87	1269.54
94.600	49000.0	99000.0	28295.3	1.287	1.292	201.3	.02642	94.60	917.10	231.32	1681.96
94.800	49000.0	99000.0	26447.6	1.733	1.720	277.5	.03470	94.80	1197.16	228.80	2260.56
95.000	49000.0	99000.0	24517.2	2.185	2.317	395.6	.04707	95.00	1592.46	226.93	3099.34
95.200	49000.0	99000.0	22500.8	3.394	3.179	582.9	.06602	95.20	2114.95	224.43	4365.50
95.400	49000.0	99000.0	20395.2	4.960	4.445	855.0	.09249	95.40	2879.06	221.83	6347.29
95.600	49000.0	99000.0	18193.8	7.555	6.332	1284.5	.13270	95.60	4025.10	219.39	9641.66
95.800	49000.0	99000.0	15885.7	12.083	9.166	1933.0	.19089	95.80	5703.34	218.03	15416.54
96.000	49000.0	99000.0	13464.7	19.775	13.547	2991.1	.28181	96.00	8186.28	217.24	26316.35



## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	49000.0	99000.0	10939.3	29.974	19.541	3732.3	.34299	96.54	17615.58	223.30	41554.90
96.400	49000.0	99000.0	8295.0	49.399	27.879	5449.3	.47630	96.88	25464.03	235.16	72409.25
	UNREFRACTED RAY STRIKES DISC										

## REFRACTION AIRMASS TABLES

## MIDLATITUDE SUMMER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	50000.0	99000.0	50000.0	.005	.005	.0	.00009	81.00	45.70	271.44	84.90
82.000	50000.0	99000.0	50000.0	.006	.006	.0	.00010	82.00	45.91	271.54	84.90
83.000	50000.0	99000.0	50000.0	.006	.007	.0	.00011	83.00	46.21	271.66	84.90
84.000	50000.0	99000.0	50000.0	.007	.008	.0	.00012	84.00	46.62	271.82	84.90
85.000	50000.0	99000.0	50000.0	.008	.009	.0	.00014	85.00	47.21	272.03	84.90
86.000	50000.0	99000.0	50000.0	.010	.011	.0	.00017	86.00	48.10	272.32	84.90
87.000	50000.0	99000.0	50000.0	.012	.013	.0	.00021	87.00	49.49	272.70	84.90
88.000	50000.0	99000.0	50000.0	.016	.017	.0	.00026	88.00	51.78	273.18	84.90
89.200	50000.0	99000.0	50000.0	.022	.023	.0	.00037	89.20	56.84	273.89	84.90
89.400	50000.0	99000.0	50000.0	.024	.025	.0	.00040	89.40	58.08	274.01	84.90
89.600	50000.0	99000.0	50000.0	.026	.027	.0	.00043	89.60	59.47	274.14	84.90
89.800	50000.0	99000.0	50000.0	.028	.029	.0	.00046	89.80	61.00	274.26	84.90
90.000	50000.0	99000.0	50000.0	.026	.031	.0	.00050	90.00	62.66	274.39	80.83
90.200	50000.0	99000.0	49960.9	.029	.034	.2	.00056	90.20	65.25	274.07	81.23
90.400	50000.0	99000.0	49843.6	.031	.037	.4	.00062	90.40	67.79	273.71	82.42
90.600	50000.0	99000.0	49648.0	.035	.040	.7	.00069	90.60	70.25	273.24	84.44
90.800	50000.0	99000.0	49374.3	.039	.044	1.0	.00077	90.80	72.60	272.59	87.46
91.000	50000.0	99000.0	49022.1	.043	.049	1.4	.00087	91.00	74.80	271.74	91.45
91.200	50000.0	99000.0	48592.1	.049	.054	1.7	.00092	91.20	80.31	271.39	96.75
91.400	50000.0	99000.0	48083.7	.054	.060	2.2	.00101	91.40	82.46	271.14	103.18
91.600	50000.0	99000.0	47497.1	.061	.067	2.8	.00113	91.60	91.99	270.93	111.35
91.800	50000.0	99000.0	46832.4	.069	.076	3.5	.00126	91.80	102.13	270.76	121.13
92.000	50000.0	99000.0	46089.4	.078	.086	4.3	.00142	92.00	105.95	270.61	133.33
92.200	50000.0	99000.0	45268.2	.089	.097	5.4	.00162	92.20	118.55	270.49	148.22
92.400	50000.0	99000.0	44368.7	.106	.113	7.9	.00212	92.40	133.13	267.70	166.26
92.600	50000.0	99000.0	43391.0	.123	.132	9.5	.00239	92.60	150.57	263.86	189.62
92.800	50000.0	99000.0	42335.1	.145	.155	11.7	.00274	92.80	171.13	262.44	218.52
93.000	50000.0	99000.0	41200.9	.171	.183	14.7	.00321	93.00	195.30	261.41	254.47
93.200	50000.0	99000.0	39988.5	.204	.217	20.4	.00406	93.20	239.75	260.62	299.51
93.400	50000.0	99000.0	38697.4	.254	.267	27.1	.00508	93.41	280.11	253.81	358.82
93.600	50000.0	99000.0	37328.1	.311	.327	34.5	.00609	93.61	332.41	251.27	435.66
93.800	50000.0	99000.0	35880.4	.385	.404	44.8	.00745	93.81	433.25	249.59	535.17
94.000	50000.0	99000.0	34353.3	.495	.510	67.4	.01041	94.01	497.39	244.54	667.80
94.200	50000.0	99000.0	32747.7	.631	.652	86.4	.01270	94.21	628.37	240.90	848.50
94.400	50000.0	99000.0	31162.9	.816	.837	116.0	.01616	94.42	793.35	238.79	1092.60
94.600	50000.0	99000.0	29296.7	1.099	1.104	178.0	.02328	94.62	1028.32	233.70	1436.08
94.800	50000.0	99000.0	27450.8	1.477	1.475	239.0	.02990	94.83	1367.93	230.03	1926.01
95.000	50000.0	99000.0	25522.8	2.018	1.984	334.6	.03992	95.04	1814.99	227.99	2628.98
95.200	50000.0	99000.0	23510.3	2.836	2.712	487.6	.05540	95.26	2464.46	225.86	3673.69
95.400	50000.0	99000.0	21405.7	4.129	3.782	723.4	.07842	95.48	3436.92	223.06	5296.13
95.600	50000.0	99000.0	19216.6	6.217	5.369	1081.5	.11202	95.71	4856.47	220.53	7933.73
95.800	50000.0	99000.0	16923.3	9.777	7.765	1635.0	.16194	95.96	6962.50	218.54	12474.23
96.000	50000.0	99000.0	14517.6	16.189	11.430	2513.1	.23783	96.24	10103.07	217.54	20938.88



## REFRACTION AIRMASS TABLES

MIDLATITUDE SUMMER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	50000.0	99000.0	11993.4	25.759	16.915	3569.4	.32545	96.53	15125.21	219.48	35214.07
96.400	50000.0	99000.0	9372.8	40.747	24.189	4795.3	.42097	96.82	21996.64	230.37	58451.92
96.600	50000.0	99000.0	6616.5	65.825	34.273	6329.8	.53627	97.14	31930.11	243.75	98004.61

UNREFRACTED RAY STRIKES DISC

AIR MASS TABLES FOR WINTER PROFILE



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	10000.0	99000.0	10000.0	1.575	1.585	.0	.03195	81.03	13388.98	217.97	25913.58
82.000	10000.0	99000.0	10000.0	1.755	1.767	.0	.03570	82.04	13442.16	217.97	25913.58
83.000	10000.0	99000.0	10000.0	1.981	1.994	.0	.04038	83.04	13515.07	217.97	25913.58
84.000	10000.0	99000.0	10000.0	2.271	2.285	.0	.04635	84.05	13618.18	217.97	25913.58
85.000	10000.0	99000.0	10000.0	2.655	2.669	.0	.05423	85.05	13769.50	217.98	25913.58
86.000	10000.0	99000.0	10000.0	3.183	3.196	.0	.06501	86.07	14001.55	217.99	25913.58
87.000	10000.0	99000.0	10000.0	3.946	3.954	.0	.08048	87.08	14376.68	218.03	25913.58
88.000	10000.0	99000.0	10000.0	5.123	5.110	.0	.10404	88.10	15022.79	218.11	25913.58
89.200	10000.0	99000.0	10000.0	7.670	7.552	.0	.15368	89.35	16579.43	218.35	25913.58
89.400	10000.0	99000.0	10000.0	8.314	8.154	.0	.16593	89.57	16989.86	218.42	25913.58
89.600	10000.0	99000.0	10000.0	9.056	8.840	.0	.17989	89.78	17465.54	218.49	25913.58
89.800	10000.0	99000.0	10000.0	9.918	9.625	.0	.19590	90.00	18016.76	218.58	25913.58
90.000	10000.0	99000.0	10000.0	10.880	10.530	44.7	.21440	90.21	18648.49	218.67	26025.50
90.200	10000.0	99000.0	9960.1	11.908	11.445	120.8	.20681	90.41	19350.38	219.31	26486.90
90.400	10000.0	99000.0	9840.3	13.110	12.493	191.9	.20166	90.60	20079.02	220.28	27266.43
90.600	10000.0	99000.0	9633.2	14.893	13.908	328.7	.24618	90.85	21093.68	221.43	28726.52
90.800	10000.0	99000.0	9333.4	16.671	15.582	489.9	.29121	91.09	22330.36	222.14	30807.30
91.000	10000.0	99000.0	8949.7	18.833	17.360	589.2	.29918	91.30	23972.55	222.87	33087.25
91.200	10000.0	99000.0	8490.5	21.471	19.498	805.0	.34368	91.54	25797.67	225.61	36535.68
91.400	10000.0	99000.0	7931.2	24.301	21.969	945.8	.36173	91.76	27872.31	227.07	40429.30
91.600	10000.0	99000.0	7291.4	28.832	25.084	1324.2	.43769	92.04	30294.33	230.36	46661.06
91.800	10000.0	99000.0	6565.5	33.942	28.474	1562.4	.46824	92.27	33404.66	233.84	53249.41
92.000	10000.0	99000.0	5745.4	38.977	32.357	1705.8	.47734	92.48	37344.04	237.47	60602.91
92.200	10000.0	99000.0	4819.9	46.645	37.405	2125.4	.54270	92.74	41713.97	241.37	72265.07
92.400	10000.0	99000.0	3802.3	57.433	43.417	2623.4	.61386	93.01	47302.41	246.27	87753.18

UNREFRACTED RAY STRIKES DISC

# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/50 M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	11000.0	99000.0	11000.0	1.348	1.358	.0	.02742	81.03	11459.93	217.67	22170.70
82.000	11000.0	99000.0	11000.0	1.502	1.513	.0	.03064	82.03	11505.59	217.67	22170.70
83.000	11000.0	99000.0	11000.0	1.696	1.708	.0	.03465	83.03	11568.16	217.66	22170.70
84.000	11000.0	99000.0	11000.0	1.945	1.956	.0	.03977	84.04	11656.64	217.66	22170.70
85.000	11000.0	99000.0	11000.0	2.274	2.285	.0	.04653	85.05	11786.45	217.66	22170.70
86.000	11000.0	99000.0	11000.0	2.727	2.736	.0	.05577	86.06	11985.44	217.66	22170.70
87.000	11000.0	99000.0	11000.0	3.382	3.384	.0	.06902	87.07	12306.91	217.68	22170.70
88.000	11000.0	99000.0	11000.0	4.392	4.371	.0	.08918	88.09	12860.14	217.74	22170.70
89.200	11000.0	99000.0	11000.0	6.576	6.452	.0	.13156	89.33	14190.69	217.95	22170.70
89.400	11000.0	99000.0	11000.0	7.126	6.964	.0	.14199	89.54	14540.98	218.01	22170.70
89.600	11000.0	99000.0	11000.0	7.760	7.546	.0	.15387	89.75	14946.67	218.08	22170.70
89.800	11000.0	99000.0	11000.0	8.495	8.212	.0	.16749	89.97	15416.39	218.16	22170.70
90.000	11000.0	99000.0	11000.0	9.303	8.979	32.6	.18320	90.18	15954.22	218.24	22215.86
90.200	11000.0	99000.0	10958.1	10.306	9.858	112.9	.19925	90.40	16617.16	218.38	22642.22
90.400	11000.0	99000.0	10832.1	11.504	10.883	203.4	.21820	90.62	17295.22	218.55	23420.26
90.600	11000.0	99000.0	10621.1	12.975	12.099	314.1	.24460	90.84	18151.23	218.73	24624.88
90.800	11000.0	99000.0	10324.1	14.428	13.541	446.7	.27498	91.07	19211.37	218.87	26334.45
91.000	11000.0	99000.0	9944.2	16.260	15.100	526.6	.27624	91.28	20647.32	219.18	28238.55
91.200	11000.0	99000.0	9487.8	18.508	16.983	719.6	.31572	91.52	22242.95	221.54	31150.84
91.400	11000.0	99000.0	8933.8	21.317	19.174	844.9	.33113	91.73	24062.80	222.67	34443.11
91.600	11000.0	99000.0	8299.8	25.137	21.897	1175.3	.39740	92.00	26179.14	225.69	39610.14
91.800	11000.0	99000.0	7580.4	29.072	24.892	1381.8	.42326	92.22	28916.77	228.93	45154.01
92.000	11000.0	99000.0	6766.9	33.215	28.309	1472.3	.42357	92.42	32047.00	232.26	51165.21
92.200	11000.0	99000.0	5850.7	39.908	32.883	1923.5	.49845	92.70	36276.00	235.96	61532.55
92.400	11000.0	99000.0	4843.9	49.001	38.236	2386.0	.56557	92.97	41229.66	240.65	74503.35
92.600	11000.0	59000.0	3744.2	60.770	44.671	2946.2	.64099	93.24	47550.55	246.33	92096.61

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	12000.0	99000.0	12000.0	1.153	1.163	.0	.02353	81.02	9805.29	217.41	18970.52
82.000	12000.0	99000.0	12000.0	1.285	1.296	.0	.02629	82.03	9844.47	217.40	18970.52
83.000	12000.0	99000.0	12000.0	1.451	1.462	.0	.02973	83.03	9898.14	217.39	18970.52
84.000	12000.0	99000.0	12000.0	1.663	1.675	.0	.03412	84.03	9974.02	217.38	18970.52
85.000	12000.0	99000.0	12000.0	1.944	1.956	.0	.03991	85.04	10085.31	217.37	18970.52
86.000	12000.0	99000.0	12000.0	2.330	2.342	.0	.04783	86.05	10255.83	217.36	18970.52
87.000	12000.0	99000.0	12000.0	2.888	2.895	.0	.05918	87.06	10531.19	217.36	18970.52
88.000	12000.0	99000.0	12000.0	3.747	3.739	.0	.07644	88.08	11004.68	217.40	18970.52
89.200	12000.0	99000.0	12000.0	5.592	5.513	.0	.11265	89.31	12141.85	217.57	18970.52
89.400	12000.0	99000.0	12000.0	6.055	5.948	.0	.12155	89.52	12440.86	217.62	18970.52
89.600	12000.0	99000.0	12000.0	6.587	6.444	.0	.13167	89.73	12786.96	217.68	18970.52
89.800	12000.0	99000.0	12000.0	7.202	7.010	.0	.14326	89.94	13187.40	217.75	18970.52
90.000	12000.0	99000.0	12000.0	7.865	7.660	23.8	.15662	90.16	13645.56	217.83	18972.48
90.200	12000.0	99000.0	11958.5	8.699	8.407	91.7	.17027	90.37	14210.75	217.96	19298.68
90.400	12000.0	99000.0	11833.9	9.691	9.275	168.0	.18636	90.59	14788.61	218.12	19915.24
90.600	12000.0	99000.0	11625.4	10.897	10.302	260.8	.20866	90.81	15517.59	218.29	20875.71
90.800	12000.0	99000.0	11332.2	12.341	11.516	371.7	.23433	91.03	16420.38	218.42	22239.66
91.000	12000.0	99000.0	10953.8	14.130	12.955	501.5	.26211	91.26	17684.50	218.55	24074.78
91.200	12000.0	99000.0	10489.6	16.058	14.684	668.8	.29764	91.50	19097.33	218.85	26561.11
91.400	12000.0	99000.0	9940.1	18.429	16.628	767.9	.30603	91.71	20691.84	219.20	29311.03
91.600	12000.0	99000.0	9311.7	21.588	19.005	1047.3	.36086	91.96	22537.30	221.71	33559.83
91.800	12000.0	99000.0	8598.3	24.911	21.653	1222.7	.38171	92.18	24941.07	224.55	38202.82
92.000	12000.0	99000.0	7790.3	28.609	24.736	1325.4	.38693	92.39	27713.63	227.44	43496.72
92.200	12000.0	99000.0	6883.2	34.810	28.793	1745.7	.45781	92.66	31441.07	230.87	52279.27
92.400	12000.0	99000.0	5886.5	41.905	33.555	2177.4	.52141	92.92	35820.37	235.29	63311.94
92.600	12000.0	99000.0	4798.6	51.286	39.126	2574.7	.57235	93.17	40989.19	240.64	76784.87

UNREFRACTED RAY STRIKES DISC

# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	13000.0	99000.0	13000.0	.986	.995	.0	.02018	81.02	8386.56	217.18	16226.48
82.000	13000.0	99000.0	13000.0	1.099	1.109	.0	.02255	82.02	8420.15	217.17	16226.48
83.000	13000.0	99000.0	13000.0	1.240	1.251	.0	.02550	83.03	8466.17	217.15	16226.48
84.000	13000.0	99000.0	13000.0	1.422	1.434	.0	.02927	84.03	8531.20	217.14	16226.48
85.000	13000.0	99000.0	13000.0	1.661	1.674	.0	.03423	85.03	8626.55	217.12	16226.48
86.000	13000.0	99000.0	13000.0	1.991	2.004	.0	.04102	86.04	8772.61	217.09	16226.48
87.000	13000.0	99000.0	13000.0	2.466	2.477	.0	.05074	87.05	9008.35	217.08	16226.48
88.000	13000.0	99000.0	13000.0	3.196	3.198	.0	.06552	88.07	9413.45	217.09	16226.48
89.200	13000.0	99000.0	13000.0	4.759	4.711	.0	.09647	89.30	10385.21	217.21	16226.48
89.400	13000.0	99000.0	13000.0	5.149	5.082	.0	.10406	89.50	10640.46	217.26	16226.48
89.600	13000.0	99000.0	13000.0	5.596	5.503	.0	.11270	89.71	10935.77	217.31	16226.48
89.800	13000.0	99000.0	13000.0	6.112	5.985	.0	.12258	89.92	11277.26	217.36	16226.48
90.000	13000.0	99000.0	13000.0	6.677	6.538	17.4	.13396	90.13	11667.72	217.43	16198.56
90.200	13000.0	99000.0	12958.9	7.355	7.172	74.9	.14558	90.35	12149.75	217.55	16453.45
90.400	13000.0	99000.0	12835.5	8.180	7.909	139.4	.15926	90.56	12642.41	217.70	16946.19
90.600	13000.0	99000.0	12629.1	9.176	8.778	217.5	.17915	90.78	13263.58	217.86	17718.94
90.800	13000.0	99000.0	12338.9	10.380	9.804	310.5	.19989	91.00	14032.85	217.99	18814.62
91.000	13000.0	99000.0	11964.8	11.821	11.019	419.7	.22361	91.22	15108.34	218.10	20294.02
91.200	13000.0	99000.0	11506.1	13.627	12.472	558.5	.25327	91.45	16080.67	218.40	22284.12
91.400	13000.0	99000.0	10960.0	15.933	14.235	729.5	.28822	91.69	17702.85	218.56	24922.82
91.600	13000.0	99000.0	10325.9	18.563	16.389	955.7	.33272	91.93	19328.57	218.89	28442.14
91.800	13000.0	99000.0	9617.9	21.320	18.730	1088.5	.34495	92.14	21433.49	220.94	32270.41
92.000	13000.0	99000.0	8815.1	24.594	21.508	1198.1	.35370	92.35	23881.85	223.17	36896.85
92.200	13000.0	99000.0	7916.4	29.914	25.107	1591.2	.42100	92.62	27157.94	226.20	44356.59
92.400	13000.0	99000.0	6929.1	36.038	29.341	1998.4	.48186	92.88	31019.22	230.28	53792.71
92.600	13000.0	99000.0	5851.6	43.736	34.288	2352.4	.52712	93.13	35590.64	235.26	65070.72
92.800	13000.0	99000.0	4674.4	56.314	40.685	3119.4	.63229	93.43	41607.34	241.26	83653.72

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
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IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	14000.0	99000.0	14000.0	.843	.852	.0	.01731	81.02	7170.55	217.00	13874.39
82.000	14000.0	99000.0	14000.0	.939	.949	.0	.01933	82.02	7199.33	216.99	13874.39
83.000	14000.0	99000.0	14000.0	1.060	1.071	.0	.02186	83.02	7238.76	216.97	13874.39
84.000	14000.0	99000.0	14000.0	1.215	1.227	.0	.02509	84.03	7294.47	216.94	13874.39
85.000	14000.0	99000.0	14000.0	1.420	1.432	.0	.02935	85.03	7376.13	216.91	13874.39
86.000	14000.0	99000.0	14000.0	1.701	1.714	.0	.03517	86.04	7501.18	216.87	13874.39
87.000	14000.0	99000.0	14000.0	2.106	2.119	.0	.04350	87.04	7702.91	216.84	13874.39
88.000	14000.0	99000.0	14000.0	2.727	2.735	.0	.05615	88.06	8049.38	216.82	13874.39
89.200	14000.0	99000.0	14000.0	4.052	4.026	.0	.08262	89.28	8879.64	216.89	13874.39
89.400	14000.0	99000.0	14000.0	4.382	4.342	.0	.08911	89.49	9097.54	216.92	13874.39
89.600	14000.0	99000.0	14000.0	4.759	4.701	.0	.09448	89.70	9349.54	216.96	13874.39
89.800	14000.0	99000.0	14000.0	5.193	5.111	.0	.10491	89.90	9640.82	217.00	13874.39
90.000	14000.0	99000.0	14000.0	5.659	5.581	.0	.11461	90.11	9973.69	217.06	13830.85
90.200	14000.0	99000.0	13959.2	6.227	6.121	12.8	.12451	90.32	10384.89	217.17	14029.36
90.400	14000.0	99000.0	13836.8	6.914	6.747	61.6	.13617	90.54	10805.04	217.31	14423.71
90.600	14000.0	99000.0	13632.1	7.743	7.484	182.1	.15219	90.75	11334.58	217.46	15052.75
90.800	14000.0	99000.0	13344.7	8.737	8.353	260.4	.17065	90.97	11990.37	217.57	15942.61
91.000	14000.0	99000.0	12974.0	9.923	9.381	352.5	.19094	91.19	12905.96	217.67	17144.74
91.200	14000.0	99000.0	12520.0	11.411	10.606	468.2	.21577	91.42	13735.31	217.95	18745.80
91.400	14000.0	99000.0	11979.9	13.258	12.091	612.4	.24578	91.65	15111.21	218.10	20866.18
91.600	14000.0	99000.0	11353.7	15.630	13.595	798.2	.28260	91.88	16493.66	218.43	23688.42
91.800	14000.0	99000.0	10638.3	18.403	16.114	1030.7	.32593	92.13	18356.27	218.75	27435.08
92.000	14000.0	99000.0	9840.5	21.125	18.598	1095.9	.37247	92.33	20505.91	219.73	31259.59
92.200	14000.0	99000.0	8949.6	25.692	21.793	1462.9	.38889	92.59	23377.67	222.11	37597.56
92.400	14000.0	99000.0	7970.9	31.437	25.567	1857.6	.44884	92.85	26775.15	225.73	45697.25
92.600	14000.0	99000.0	6903.0	37.516	29.944	2159.3	.48637	93.09	30803.20	230.23	55156.55
92.800	14000.0	99000.0	5743.9	46.213	35.266	2568.9	.53772	93.34	35981.97	235.98	67887.94
93.000	14000.0	99000.0	4462.8	62.428	42.581	3683.7	.68876	93.69	42565.73	241.95	92314.65

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	15000.0	99000.0	15000.0	.720	.729	.0	.01484	81.01	6128.66	216.88	11858.97
82.000	15000.0	99000.0	15000.0	.803	.812	.0	.01657	82.02	6153.32	216.86	11858.97
83.000	15000.0	99000.0	15000.0	.906	.916	.0	.01874	83.02	6187.09	216.83	11858.97
84.000	15000.0	99000.0	15000.0	1.038	1.049	.0	.02151	84.02	6234.79	216.80	11858.97
85.000	15000.0	99000.0	15000.0	1.213	1.225	.0	.02516	85.03	6304.70	216.75	11858.97
86.000	15000.0	99000.0	15000.0	1.453	1.466	.0	.03014	86.03	6411.71	216.70	11858.97
87.000	15000.0	99000.0	15000.0	1.798	1.812	.0	.03728	87.04	6584.28	216.64	11858.97
88.000	15000.0	99000.0	15000.0	2.327	2.338	.0	.04812	88.05	6880.51	216.59	11858.97
89.200	15000.0	99000.0	15000.0	3.451	3.440	.0	.07076	89.27	7589.75	216.60	11858.97
89.400	15000.0	99000.0	15000.0	3.730	3.710	.0	.07631	89.48	7775.76	216.62	11858.97
89.600	15000.0	99000.0	15000.0	4.049	4.016	.0	.08261	89.68	7990.81	216.64	11858.97
89.800	15000.0	99000.0	15000.0	4.415	4.365	.0	.08980	89.89	8239.28	216.67	11858.97
90.000	15000.0	99000.0	15000.0	4.800	4.766	9.4	.09808	90.10	8523.11	216.71	11806.66
90.200	15000.0	99000.0	14959.5	5.277	5.225	50.8	.10653	90.31	8873.95	216.81	11962.41
90.400	15000.0	99000.0	14837.9	5.853	5.758	97.2	.11646	90.52	9232.32	216.93	12281.89
90.600	15000.0	99000.0	14634.7	6.543	6.384	152.9	.13008	90.73	9683.88	217.07	12793.38
90.800	15000.0	99000.0	14349.5	7.370	7.120	219.0	.14577	90.95	10243.11	217.17	13523.41
91.000	15000.0	99000.0	13981.8	8.351	7.992	297.0	.16317	91.16	11022.98	217.26	14507.16
91.200	15000.0	99000.0	13531.7	9.572	9.027	393.7	.18401	91.38	11730.63	217.53	15809.03
91.400	15000.0	99000.0	12996.7	11.080	10.282	516.4	.21003	91.61	12898.89	217.66	17527.14
91.600	15000.0	99000.0	12377.0	12.989	11.798	669.3	.24040	91.84	14075.34	217.98	19786.08
91.800	15000.0	99000.0	11669.9	15.444	13.659	861.5	.27660	92.08	15654.16	218.29	22771.80
92.000	15000.0	99000.0	10872.2	18.419	15.975	1113.4	.32214	92.32	17546.73	218.56	26811.49
92.200	15000.0	99000.0	9982.1	22.116	18.825	1377.9	.36523	92.57	20054.87	218.94	31916.59
92.400	15000.0	99000.0	9012.2	27.264	22.222	1794.4	.42967	92.83	22786.36	221.83	39081.95
92.600	15000.0	99000.0	7952.4	32.204	26.058	2001.7	.45141	93.05	26573.34	225.67	46766.28
92.800	15000.0	99000.0	6803.8	38.926	30.666	2248.5	.47830	93.28	30799.74	230.83	56562.42
93.000	15000.0	99000.0	5544.0	51.772	36.998	3204.0	.60936	93.61	36501.92	236.74	75643.19

UNREFRACTED RAY STRIKES DISC



# REFRACTION AIRMASS TABLES

LATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	16000.0	99000.0	16000.0	.615	.623	.0	.01271	81.01	5236.29	216.82	10132.66
82.000	16000.0	99000.0	16000.0	.686	.694	.0	.01420	82.01	5257.41	216.80	10132.66
83.000	16000.0	99000.0	16000.0	.774	.783	.0	.01606	83.02	5286.32	216.76	10132.66
84.000	16000.0	99000.0	16000.0	.887	.897	.0	.01844	84.02	5327.16	216.72	10132.66
85.000	16000.0	99000.0	16000.0	1.036	1.048	.0	.02156	85.02	5386.98	216.67	10132.66
86.000	16000.0	99000.0	16000.0	1.241	1.254	.0	.02583	86.03	5478.53	216.60	10132.66
87.000	16000.0	99000.0	16000.0	1.535	1.549	.0	.03195	87.03	5626.10	216.51	10132.66
88.000	16000.0	99000.0	16000.0	1.986	1.999	.0	.04123	88.04	5879.30	216.42	10132.66
89.200	16000.0	99000.0	16000.0	2.941	2.939	.0	.06061	89.26	6485.04	216.35	10132.66
89.400	16000.0	99000.0	16000.0	3.177	3.169	.0	.06535	89.47	6643.81	216.36	10132.66
89.600	16000.0	99000.0	16000.0	3.446	3.430	.0	.07073	89.67	6827.33	216.37	10132.66
89.800	16000.0	99000.0	16000.0	3.756	3.728	.0	.07688	89.88	7039.29	216.38	10132.66
90.000	16000.0	99000.0	16000.0	4.074	4.069	6.9	.08394	90.08	7281.34	216.41	10075.97
90.200	16000.0	99000.0	15959.7	4.476	4.461	42.1	.09116	90.29	7580.70	216.48	10193.06
90.400	16000.0	99000.0	15838.8	4.960	4.915	81.5	.09964	90.50	7886.40	216.59	10459.46
90.600	16000.0	99000.0	15636.9	5.537	5.447	128.7	.11123	90.71	8271.54	216.71	10879.50
90.800	16000.0	99000.0	15353.5	6.228	6.072	184.7	.12458	90.92	8748.53	216.79	11480.28
91.000	16000.0	99000.0	14988.4	7.041	6.812	250.9	.13952	91.14	9413.07	216.86	12287.97
91.200	16000.0	99000.0	14541.6	8.052	7.689	332.0	.15705	91.36	10017.00	217.12	13356.57
91.400	16000.0	99000.0	14010.9	9.291	8.751	436.2	.17946	91.58	10862.85	217.24	14759.56
91.600	16000.0	99000.0	13396.6	10.841	10.029	563.1	.20475	91.80	12011.58	217.54	16583.68
91.800	16000.0	99000.0	12696.4	12.819	11.595	722.6	.23507	92.04	13351.27	217.84	18979.58
92.000	16000.0	99000.0	11907.5	15.423	13.540	934.6	.27401	92.27	14958.10	218.09	22196.61
92.200	16000.0	99000.0	11027.9	18.698	15.986	1229.2	.32572	92.53	16895.45	218.45	26650.05
92.400	16000.0	99000.0	10053.5	23.083	19.085	1609.7	.38806	92.79	19512.62	218.86	32683.49
92.600	16000.0	99000.0	8999.3	28.342	22.644	1951.3	.43472	93.03	22866.80	221.77	40047.79
92.800	16000.0	99000.0	7859.9	33.244	26.656	2058.2	.43913	93.24	26565.57	226.14	47729.33
93.000	16000.0	99000.0	6618.8	42.811	32.062	2776.6	.53675	93.54	31522.19	231.82	62218.78
93.200	16000.0	99000.0	5260.1	57.563	38.966	3732.2	.65883	93.86	37652.50	237.62	83942.11

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SC M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	17000.0	99000.0	17000.0	.525	.533	.0	.01089	81.01	4472.26	216.84	8654.50
82.000	17000.0	99000.0	17000.0	.586	.594	.0	.01217	82.01	4490.34	216.81	8654.50
83.000	17000.0	99000.0	17000.0	.661	.670	.0	.01376	83.01	4515.08	216.77	8654.50
84.000	17000.0	99000.0	17000.0	.757	.767	.0	.01579	84.02	4550.03	216.72	8654.50
85.000	17000.0	99000.0	17000.0	.885	.896	.0	.01847	85.02	4601.21	216.65	8654.50
86.000	17000.0	99000.0	17000.0	1.059	1.072	.0	.02213	86.02	4679.50	216.56	8654.50
87.000	17000.0	99000.0	17000.0	1.310	1.324	.0	.02737	87.03	4805.66	216.45	8654.50
88.000	17000.0	99000.0	17000.0	1.694	1.708	.0	.03532	88.04	5022.01	216.32	8654.50
89.200	17000.0	99000.0	17000.0	2.506	2.511	.0	.05192	89.25	5539.28	216.17	8654.50
89.400	17000.0	99000.0	17000.0	2.706	2.707	.0	.05597	89.46	5674.79	216.16	8654.50
89.600	17000.0	99000.0	17000.0	2.935	2.930	.0	.06057	89.66	5831.38	216.15	8654.50
89.800	17000.0	99000.0	17000.0	3.197	3.184	.0	.06583	89.87	6012.20	216.14	8654.50
90.000	17000.0	99000.0	17000.0	3.459	3.475	5.0	.07186	90.07	6218.63	216.15	8596.29
90.200	17000.0	99000.0	16959.9	3.799	3.809	35.1	.07803	90.28	6474.06	216.20	8694.24
90.400	17000.0	99000.0	16839.6	4.206	4.196	68.6	.08526	90.49	6734.84	216.29	8907.64
90.600	17000.0	99000.0	16638.8	4.691	4.648	108.6	.09514	90.70	7063.36	216.38	9254.35
90.800	17000.0	99000.0	16357.0	5.269	5.180	156.1	.10652	90.91	7470.26	216.44	9751.29
91.000	17000.0	99000.0	15994.0	5.948	5.809	212.4	.11937	91.12	8036.70	216.50	10419.53
91.200	17000.0	99000.0	15549.9	6.786	6.553	280.6	.13412	91.33	8552.17	216.73	11298.23
91.400	17000.0	99000.0	15022.9	7.810	7.452	368.5	.15315	91.55	9273.10	216.84	12451.61
91.600	17000.0	99000.0	14413.1	9.082	8.534	475.1	.17456	91.77	10249.91	217.12	13940.92
91.800	17000.0	99000.0	13718.7	10.703	9.855	607.9	.19999	92.00	11387.69	217.40	15876.64
92.000	17000.0	99000.0	12937.2	12.804	11.494	787.2	.23343	92.23	12753.03	217.63	18460.66
92.200	17000.0	99000.0	12067.3	15.613	13.541	1029.8	.27641	92.48	14398.86	217.98	21970.62
92.400	17000.0	99000.0	11105.4	19.135	16.124	1343.1	.32844	92.73	16611.90	218.39	26797.20
92.600	17000.0	99000.0	10046.6	24.006	19.446	1769.6	.39542	93.00	19353.36	218.83	33497.61
92.800	17000.0	99000.0	8912.6	28.764	23.074	1897.6	.40483	93.20	22836.22	222.06	40238.40
93.000	17000.0	99000.0	7687.5	36.002	27.694	2386.2	.46903	93.47	27131.58	227.27	51117.79
93.200	17000.0	99000.0	6345.2	47.717	33.750	3263.6	.58397	93.78	32522.89	232.69	68721.24
93.400	17000.0	99000.0	4901.3	60.437	40.766	3716.4	.63366	94.03	39388.86	238.74	87686.34

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	18000.0	99000.0	18000.0	.449	.455	.0	.00933	81.01	3818.34	216.95	7389.28
82.000	18000.0	99000.0	18000.0	.500	.507	.0	.01042	82.01	3833.81	216.92	7389.28
83.000	18000.0	99000.0	18000.0	.564	.572	.0	.01179	83.01	3854.99	216.87	7389.28
84.000	18000.0	99000.0	18000.0	.646	.656	.0	.01353	84.01	3884.88	216.81	7389.28
85.000	18000.0	99000.0	18000.0	.755	.765	.0	.01582	85.02	3928.66	216.73	7389.28
86.000	18000.0	99000.0	18000.0	.904	.916	.0	.01896	86.02	3995.59	216.62	7389.28
87.000	18000.0	99000.0	18000.0	1.118	1.131	.0	.02345	87.02	4103.41	216.48	7389.28
88.000	18000.0	99000.0	18000.0	1.445	1.459	.0	.03026	88.03	4288.24	216.30	7389.28
89.200	18000.0	99000.0	18000.0	2.135	2.145	.0	.04447	89.24	4729.85	216.07	7389.28
89.400	18000.0	99000.0	18000.0	2.306	2.312	.0	.04794	89.45	4845.50	216.03	7389.28
89.600	18000.0	99000.0	18000.0	2.499	2.502	.0	.05188	89.65	4979.11	216.00	7389.28
89.800	18000.0	99000.0	18000.0	2.721	2.719	.0	.05638	89.86	5133.37	215.97	7389.28
90.000	18000.0	99000.0	18000.0	2.938	2.967	3.7	.06154	90.06	5309.41	215.95	7331.41
90.200	18000.0	99000.0	17960.1	3.225	3.252	29.3	.06681	90.27	5527.37	215.97	7409.86
90.400	18000.0	99000.0	17840.3	3.569	3.582	57.9	.07298	90.47	5749.82	216.03	7585.60
90.600	18000.0	99000.0	17640.3	3.977	3.967	91.9	.08140	90.68	6030.05	216.10	7873.05
90.800	18000.0	99000.0	17359.9	4.461	4.420	132.2	.09110	90.89	6377.17	216.14	8284.11
91.000	18000.0	99000.0	16998.8	5.032	4.955	180.3	.10224	91.10	6860.12	216.16	8841.30
91.200	18000.0	99000.0	16557.0	5.730	5.587	237.7	.11459	91.31	7300.08	216.38	9569.02
91.400	18000.0	99000.0	16033.0	6.579	6.350	311.9	.13078	91.53	7914.71	216.46	10519.12
91.600	18000.0	99000.0	15427.1	7.640	7.267	401.7	.14894	91.75	8745.83	216.72	11742.43
91.800	18000.0	99000.0	14737.5	8.956	8.384	512.5	.17024	91.97	9712.83	216.98	13321.94
92.000	18000.0	99000.0	13962.2	10.665	9.768	665.1	.19912	92.20	10873.78	217.19	15417.58
92.200	18000.0	99000.0	13100.3	12.911	11.488	865.8	.23495	92.43	12273.23	217.54	18215.78
92.400	18000.0	99000.0	12148.7	15.929	13.652	1125.5	.27859	92.68	14146.95	217.92	22019.47
92.600	18000.0	99000.0	11103.4	19.825	16.418	1476.4	.33445	92.93	16467.16	218.35	27354.69
92.800	18000.0	99000.0	9961.7	24.631	19.881	1786.0	.37868	93.18	19563.32	218.89	34004.73
93.000	18000.0	99000.0	8750.3	29.400	23.746	1918.3	.38915	93.39	22992.84	223.20	41308.36
93.200	18000.0	99000.0	7422.7	39.641	29.158	2855.1	.51701	93.72	28004.43	228.11	56469.94
93.400	18000.0	99000.0	5987.0	52.126	35.682	3592.5	.60651	94.01	34136.01	233.61	75114.11

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	19000.0	99000.0	19000.0	.383	.389	.0	.00799	81.01	3258.86	217.17	6306.72
82.000	19000.0	99000.0	19000.0	.427	.433	.0	.00893	82.01	3272.10	217.13	6306.72
83.000	19000.0	99000.0	19000.0	.481	.489	.0	.01009	83.01	3290.21	217.08	6306.72
84.000	19000.0	99000.0	19000.0	.552	.560	.0	.01158	84.01	3315.78	217.01	6306.72
85.000	19000.0	99000.0	19000.0	.644	.654	.0	.01355	85.01	3353.21	216.91	6306.72
86.000	19000.0	99000.0	19000.0	.771	.782	.0	.01623	86.02	3410.42	216.78	6306.72
87.000	19000.0	99000.0	19000.0	.954	.966	.0	.02008	87.02	3502.54	216.62	6306.72
88.000	19000.0	99000.0	19000.0	1.233	1.246	.0	.02392	88.03	3660.36	216.40	6306.72
89.200	19000.0	99000.0	19000.0	1.820	1.831	.0	.03811	89.24	4037.30	216.07	6306.72
89.400	19000.0	99000.0	19000.0	1.965	1.974	.0	.04109	89.44	4135.98	216.01	6306.72
89.600	19000.0	99000.0	19000.0	2.129	2.136	.0	.04447	89.64	4249.98	215.96	6306.72
89.800	19000.0	99000.0	19000.0	2.317	2.321	.0	.04832	89.85	4381.57	215.90	6306.72
90.000	19000.0	99000.0	19000.0	2.496	2.533	2.7	.05273	90.05	4531.72	215.84	6250.36
90.200	19000.0	99000.0	18960.2	2.739	2.776	24.6	.05723	90.26	4717.69	215.83	6313.61
90.400	19000.0	99000.0	18840.9	3.030	3.057	48.9	.06251	90.46	4907.44	215.85	6458.96
90.600	19000.0	99000.0	18641.7	3.374	3.385	77.9	.06968	90.67	5146.48	215.88	6698.19
90.800	19000.0	99000.0	18362.4	3.782	3.771	112.1	.07795	90.88	5442.62	215.88	7040.82
91.000	19000.0	99000.0	18002.8	4.261	4.227	153.2	.08754	91.09	5765.85	215.87	7505.57
91.200	19000.0	99000.0	17563.0	4.845	4.765	201.6	.09796	91.30	6229.94	216.06	8111.05
91.400	19000.0	99000.0	17041.6	5.552	5.413	264.5	.11174	91.51	6754.04	216.12	8899.08
91.600	19000.0	99000.0	16438.8	6.433	6.191	340.4	.12717	91.73	7461.55	216.35	9910.03
91.800	19000.0	99000.0	15753.4	7.517	7.138	432.1	.14480	91.94	8178.24	216.58	11206.23
92.000	19000.0	99000.0	14983.3	8.920	8.309	563.5	.17006	92.17	9271.62	216.77	12920.82
92.200	19000.0	99000.0	14128.2	10.735	9.758	730.1	.19997	92.40	10462.44	217.10	15175.83
92.400	19000.0	99000.0	13185.1	13.143	11.577	946.5	.23671	92.64	12050.62	217.47	18204.19
92.600	19000.0	99000.0	12151.0	16.430	13.893	1237.2	.28353	92.88	14016.70	217.88	22401.80
92.800	19000.0	99000.0	11021.3	20.818	16.884	1634.5	.34408	93.14	16465.95	218.33	28370.69
93.000	19000.0	99000.0	9803.9	25.356	20.454	1765.8	.35747	93.36	19703.42	219.74	34701.98
93.200	19000.0	99000.0	8493.0	33.014	25.113	2501.0	.45749	93.66	24035.09	224.01	46502.43
93.400	19000.0	99000.0	7072.6	43.980	30.972	3322.2	.56024	93.96	29164.24	229.00	62968.91
93.600	19000.0	99000.0	5566.3	57.285	37.832	3921.7	.62494	94.22	35735.31	236.14	82705.14

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## LATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M.N. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	20000.0	99000.0	20000.0	.327	.332	.0	.00682	81.01	2780.48	217.52	5380.77
82.000	20000.0	99000.0	20000.0	.364	.370	.0	.00762	82.01	2791.80	217.47	5380.77
83.000	20000.0	99000.0	20000.0	.411	.418	.0	.00862	83.01	2807.30	217.41	5380.77
84.000	20000.0	99000.0	20000.0	.471	.478	.0	.00989	84.01	2829.16	217.33	5380.77
85.000	20000.0	99000.0	20000.0	.550	.558	.0	.01157	85.01	2861.15	217.23	5380.77
86.000	20000.0	99000.0	20000.0	.658	.668	.0	.01386	86.01	2910.03	217.08	5380.77
87.000	20000.0	99000.0	20000.0	.814	.825	.0	.01714	87.02	2988.69	216.88	5380.77
88.000	20000.0	99000.0	20000.0	1.051	1.064	.0	.02212	88.02	3123.39	216.63	5380.77
89.000	20000.0	99000.0	20000.0	1.551	1.563	.0	.03252	89.23	3444.85	216.25	5380.77
89.400	20000.0	99000.0	20000.0	1.674	1.684	.0	.03506	89.44	3528.96	216.18	5380.77
89.600	20000.0	99000.0	20000.0	1.814	1.823	.0	.03793	89.64	3626.11	216.11	5380.77
89.800	20000.0	99000.0	20000.0	1.973	1.980	.0	.04121	89.84	3738.23	216.04	5380.77
90.000	20000.0	99000.0	20000.0	2.114	2.160	2.0	.04497	90.04	3866.13	215.97	5327.04
90.200	20000.0	99000.0	19960.3	2.326	2.368	20.8	.04929	90.25	4024.93	215.90	5376.74
90.400	20000.0	99000.0	19841.2	2.574	2.608	42.0	.05430	90.45	4187.13	215.83	5495.23
90.600	20000.0	99000.0	19642.5	2.865	2.889	66.5	.06014	90.66	4391.19	215.77	5698.95
90.800	20000.0	99000.0	19364.2	3.208	3.218	95.4	.06700	90.87	4643.86	215.71	5985.33
91.000	20000.0	99000.0	19005.9	3.611	3.606	130.3	.07509	91.08	4919.65	215.65	6373.96
91.200	20000.0	99000.0	18567.7	4.102	4.064	171.4	.08392	91.28	5315.58	215.79	6879.76
91.400	20000.0	99000.0	18048.5	4.693	4.616	224.7	.09563	91.50	5762.54	215.81	7536.06
91.600	20000.0	99000.0	17448.5	5.428	5.277	288.9	.10874	91.71	6365.10	216.01	8375.53
91.800	20000.0	99000.0	16766.5	6.327	6.081	366.6	.12378	91.92	6976.84	216.20	9448.35
92.000	20000.0	99000.0	16000.9	7.483	7.074	479.7	.14574	92.15	7806.44	216.37	10857.26
92.200	20000.0	99000.0	15151.3	8.961	8.298	617.2	.17046	92.37	8919.47	216.69	12688.92
92.400	20000.0	99000.0	14215.4	10.907	9.832	798.4	.20148	92.60	10266.97	217.04	15130.84
92.600	20000.0	99000.0	13190.6	13.537	11.777	1040.6	.24086	92.84	11934.76	217.43	18460.62
92.800	20000.0	99000.0	12073.1	17.194	14.278	1369.4	.29157	93.09	14013.28	217.87	23148.62
93.000	20000.0	99000.0	10858.6	22.094	17.527	1797.8	.35373	93.35	16831.00	218.39	29809.48
93.200	20000.0	99000.0	9556.4	27.887	21.549	2202.0	.40589	93.61	20352.51	220.62	38319.29
93.400	20000.0	99000.0	8150.8	36.898	26.675	2918.6	.49685	93.90	25051.89	224.79	51606.53
93.600	20000.0	99000.0	6660.0	46.876	32.666	3364.6	.54462	94.14	30796.39	231.25	66827.91
93.800	20000.0	99000.0	5030.0	68.057	41.107	4764.4	.70502	94.51	38290.80	237.93	98463.20

UNREFRACTED RAY STRIKES OISC

## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	21000.0	99000.0	21000.0	.279	.284	.0	.00583	81.01	2372.37	217.93	4590.98
82.000	21000.0	99000.0	21000.0	.311	.316	.0	.00651	82.01	2382.07	217.88	4590.98
83.000	21000.0	99000.0	21000.0	.350	.357	.0	.00736	83.01	2395.32	217.81	4590.98
84.000	21000.0	99000.0	21000.0	.401	.409	.0	.00845	84.01	2414.02	217.72	4590.98
85.000	21000.0	99000.0	21000.0	.469	.477	.0	.00988	85.01	2441.37	217.60	4590.98
86.000	21000.0	99000.0	21000.0	.561	.571	.0	.01184	86.01	2483.13	217.43	4590.98
87.000	21000.0	99000.0	21000.0	.694	.705	.0	.01464	87.01	2550.30	217.21	4590.98
88.000	21000.0	99000.0	21000.0	.896	.908	.0	.01889	88.02	2665.26	216.91	4590.98
89.200	21000.0	99000.0	21000.0	1.321	1.334	.0	.02775	89.23	2939.42	216.46	4590.98
89.400	21000.0	99000.0	21000.0	1.425	1.438	.0	.02992	89.43	3011.12	216.37	4590.98
89.600	21000.0	99000.0	21000.0	1.544	1.555	.0	.03237	89.63	3093.93	216.29	4590.98
89.800	21000.0	99000.0	21000.0	1.680	1.689	.0	.03516	89.84	3189.47	216.21	4590.98
90.000	21000.0	99000.0	21000.0	1.795	1.843	1.4	.03836	90.04	3298.43	216.12	4540.04
90.200	21000.0	99000.0	20960.4	1.974	2.020	17.4	.04204	90.24	3433.72	216.04	4580.27
90.400	21000.0	99000.0	20841.6	2.184	2.225	35.4	.04631	90.45	3571.89	215.96	4682.06
90.600	21000.0	99000.0	20643.5	2.429	2.463	56.2	.05127	90.65	3745.74	215.88	4848.87
90.800	21000.0	99000.0	20366.0	2.718	2.743	80.8	.05710	90.86	3960.97	215.81	5088.35
91.000	21000.0	99000.0	20008.9	3.063	3.073	110.4	.06397	91.06	4195.89	215.74	5413.20
91.200	21000.0	99000.0	19571.9	3.478	3.465	146.5	.07215	91.27	4534.08	215.67	5838.33
91.400	21000.0	99000.0	19054.5	3.973	3.935	191.3	.08194	91.48	4915.45	215.61	6386.45
91.600	21000.0	99000.0	18456.8	4.586	4.498	245.7	.09304	91.69	5428.85	215.75	7084.57
91.800	21000.0	99000.0	17777.6	5.336	5.182	311.6	.10586	91.91	5951.03	215.89	7976.28
92.000	21000.0	99000.0	17015.8	6.293	6.024	407.0	.12447	92.12	6657.85	216.03	9140.17
92.200	21000.0	99000.0	16171.0	7.508	7.061	522.9	.14543	92.35	7604.10	216.31	10642.74
92.400	21000.0	99000.0	15241.1	9.092	8.358	675.1	.17167	92.57	8748.29	216.64	12625.64
92.600	21000.0	99000.0	14224.0	11.208	9.997	877.8	.20491	92.80	10164.29	217.00	15299.54
92.800	21000.0	99000.0	13116.7	14.102	12.097	1151.5	.24754	93.05	11929.91	217.42	19005.04
93.000	21000.0	99000.0	11915.2	18.201	14.816	1510.6	.30032	93.30	14312.70	217.90	24253.97
93.200	21000.0	99000.0	10613.7	23.606	18.412	2032.4	.37311	93.57	17369.37	218.51	32024.49
93.400	21000.0	99000.0	9221.4	30.675	22.896	2575.1	.44151	93.84	21448.19	221.19	42401.48
93.600	21000.0	99000.0	7744.4	37.890	28.061	2764.0	.45841	94.06	26428.55	226.72	53437.37
93.800	21000.0	99000.0	6135.2	55.175	35.511	4165.2	.62349	94.42	33034.60	233.01	79352.11

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SO M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	22000.0	99000.0	22000.0	.238	.242	.0	.00498	81.00	2024.23	218.41	3917.12
82.000	22000.0	99000.0	22000.0	.265	.270	.0	.00556	82.01	2032.52	218.35	3917.12
83.000	22000.0	99000.0	22000.0	.299	.305	.0	.00629	83.01	2043.86	218.28	3917.12
84.000	22000.0	99000.0	22000.0	.342	.349	.0	.00722	84.01	2059.86	218.17	3917.12
85.000	22000.0	99000.0	22000.0	.400	.407	.0	.00844	85.01	2083.24	218.04	3917.12
86.000	22000.0	99000.0	22000.0	.479	.487	.0	.01011	86.01	2118.93	217.85	3917.12
87.000	22000.0	99000.0	22000.0	.592	.602	.0	.01250	87.01	2176.30	217.59	3917.12
88.000	22000.0	99000.0	22000.0	.764	.776	.0	.01613	88.02	2274.42	217.24	3917.12
89.200	22000.0	99000.0	22000.0	1.126	1.138	.0	.02369	89.22	2508.24	216.71	3917.12
89.400	22000.0	99000.0	22000.0	1.214	1.227	.0	.02554	89.43	2569.37	216.61	3917.12
89.600	22000.0	99000.0	22000.0	1.315	1.327	.0	.02763	89.63	2639.96	216.51	3917.12
89.800	22000.0	99000.0	22000.0	1.430	1.442	.0	.03001	89.83	2721.38	216.41	3917.12
90.000	22000.0	99000.0	22000.0	1.524	1.573	1.0	.03273	90.03	2814.23	216.31	3869.21
90.200	22000.0	99000.0	21960.5	1.676	1.723	14.6	.03587	90.24	2929.50	216.21	3901.96
90.400	22000.0	99000.0	21842.0	1.854	1.898	30.0	.03950	90.44	3047.23	216.12	3986.84
90.600	22000.0	99000.0	21644.4	2.061	2.101	47.6	.04372	90.64	3195.37	216.02	4126.56
90.800	22000.0	99000.0	21367.6	2.305	2.339	68.5	.04868	90.85	3378.74	215.93	4327.40
91.000	22000.0	99000.0	21011.4	2.596	2.619	93.6	.05452	91.05	3578.89	215.85	4599.80
91.200	22000.0	99000.0	20575.6	2.943	2.953	124.2	.06147	91.26	3866.86	215.77	4954.57
91.400	22000.0	99000.0	20059.9	3.365	3.352	162.1	.06978	91.47	4191.51	215.70	5413.83
91.600	22000.0	99000.0	19463.9	3.881	3.833	209.8	.07982	91.68	4629.38	215.63	5999.24
91.800	22000.0	99000.0	18787.1	4.508	4.416	265.4	.09062	91.89	5075.18	215.67	6742.92
92.000	22000.0	99000.0	18028.5	5.303	5.132	345.9	.10638	92.11	5677.58	215.75	7707.83
92.200	22000.0	99000.0	17187.6	6.306	6.012	443.8	.12417	92.32	6482.51	215.98	8945.88
92.400	22000.0	99000.0	16262.8	7.607	7.110	572.0	.14641	92.55	7365.79	216.27	10571.56
92.600	22000.0	99000.0	15252.2	9.324	8.495	742.2	.17453	92.77	8553.72	216.61	12737.14
92.800	22000.0	99000.0	14153.3	11.656	10.264	971.2	.21048	93.01	10158.85	217.00	15700.25
93.000	22000.0	99000.0	12962.8	14.885	12.548	1274.5	.25558	93.26	12176.00	217.44	19845.97
93.200	22000.0	99000.0	11676.3	19.352	15.544	1697.9	.31523	93.52	14759.52	218.04	25934.94
93.400	22000.0	99000.0	10284.9	25.687	19.568	2315.9	.39776	93.80	18098.91	218.61	35073.48
93.600	22000.0	99000.0	8815.3	32.015	24.178	2444.3	.40828	94.01	22442.62	222.48	44072.75
93.800	22000.0	99000.0	7229.7	45.327	30.615	3645.6	.51115	94.35	28410.43	228.43	64353.31
94.000	22000.0	99000.0	5546.2	61.845	38.310	4452.0	.63613	94.64	35516.82	236.02	88702.82

UNREFRACTED RAY STRIKES DISC



# REACTRION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	23000.0	99000.0	23000.0	.203	.207	.0	.00425	81.00	1727.23	218.98	3342.16
82.000	23000.0	99000.0	23000.0	.226	.231	.0	.00475	82.00	1734.33	218.91	3342.16
83.000	23000.0	99000.0	23000.0	.255	.260	.0	.00537	83.01	1744.04	218.83	3342.16
84.000	23000.0	99000.0	23000.0	.292	.298	.0	.00616	84.01	1757.72	218.71	3342.16
85.000	23000.0	99000.0	23000.0	.341	.348	.0	.00721	85.01	1777.72	218.56	3342.16
86.000	23000.0	99000.0	23000.0	.408	.416	.0	.00863	86.01	1808.22	218.35	3342.16
87.000	23000.0	99000.0	23000.0	.505	.514	.0	.01068	87.01	1857.22	218.05	3342.16
88.000	23000.0	99000.0	23000.0	.651	.662	.0	.01377	88.01	1940.98	217.65	3342.16
89.200	23000.0	99000.0	23000.0	.959	.972	.0	.02023	89.22	2140.41	217.02	3342.16
89.400	23000.0	99000.0	23000.0	1.035	1.047	.0	.02180	89.42	2192.53	216.90	3342.16
89.600	23000.0	99000.0	23000.0	1.120	1.133	.0	.02358	89.62	2252.70	216.78	3342.16
89.800	23000.0	99000.0	23000.0	1.218	1.231	.0	.02561	89.83	2322.11	216.66	3342.16
90.000	23000.0	99000.0	23000.0	1.295	1.342	.8	.02793	90.03	2401.24	216.54	3297.39
90.200	23000.0	99000.0	22960.6	1.424	1.471	12.3	.03061	90.23	2459.46	216.42	3324.19
90.400	23000.0	99000.0	22842.3	1.574	1.619	25.4	.03370	90.43	2599.78	216.31	3395.19
90.600	23000.0	99000.0	22645.1	1.750	1.792	40.4	.03730	90.64	2726.04	216.19	3512.52
90.800	23000.0	99000.0	22368.9	1.956	1.995	58.1	.04152	90.84	2882.29	216.09	3681.34
91.000	23000.0	99000.0	22013.5	2.201	2.234	79.4	.04649	91.05	3052.85	215.98	3909.25
91.200	23000.0	99000.0	21578.8	2.494	2.517	105.4	.05239	91.25	3298.12	215.89	4208.16
91.400	23000.0	99000.0	21064.5	2.849	2.856	137.6	.05946	91.46	3574.57	215.80	4593.18
91.600	23000.0	99000.0	20470.1	3.281	3.265	177.9	.06797	91.67	3946.96	215.71	5082.67
91.800	23000.0	99000.0	19795.3	3.814	3.762	229.0	.07833	91.88	4327.32	215.64	5707.78
92.000	23000.0	99000.0	19039.3	4.475	4.372	294.6	.09103	92.09	4840.94	215.57	6507.47
92.200	23000.0	99000.0	18201.7	5.309	5.120	377.3	.10609	92.31	5526.00	215.73	7535.39
92.400	23000.0	99000.0	17281.2	6.382	6.052	485.6	.12496	92.52	6279.31	215.95	8873.21
92.600	23000.0	99000.0	16276.0	7.789	7.225	628.9	.14719	92.75	7290.47	216.25	10644.44
92.800	23000.0	99000.0	15184.2	9.675	8.718	821.1	.17919	92.98	8652.32	216.60	13036.42
93.000	23000.0	99000.0	14002.8	12.266	10.644	1082.2	.21843	93.22	10239.15	217.01	16359.49
93.200	23000.0	99000.0	12728.7	15.938	13.150	1422.4	.26667	93.47	12547.75	217.58	21066.44
93.400	23000.0	99000.0	11354.1	21.211	16.499	1934.5	.33596	93.74	15375.38	218.14	28230.16
93.600	23000.0	99000.0	9879.6	27.175	20.790	2271.2	.37739	93.98	19209.24	219.14	36942.50
93.800	23000.0	99000.0	8314.3	37.798	26.325	3196.6	.48729	94.29	24122.69	224.30	52421.19
94.000	23000.0	99000.0	6648.8	49.830	33.035	3821.0	.55366	94.55	30588.21	231.15	71032.60
94.200	23000.0	99000.0	4853.6	68.726	41.725	4633.3	.63920	94.84	38889.30	238.63	99024.75

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (IEFF) (10)	T (IEFF) (11)	P (TAN) (12)
81.000	24000.0	99000.0	24000.0	.173	.177	.0	.00363	81.00	1473.86	219.64	2851.60
82.000	24000.0	99000.0	24000.0	.193	.197	.0	.00406	82.00	1479.95	219.57	2851.60
83.000	24000.0	99000.0	24000.0	.218	.222	.0	.00459	83.00	1488.26	219.48	2851.60
84.000	24000.0	99000.0	24000.0	.249	.255	.0	.00526	84.01	1499.97	219.35	2851.60
85.000	24000.0	99000.0	24000.0	.291	.297	.0	.00616	85.01	1517.08	219.18	2851.60
86.000	24000.0	99000.0	24000.0	.348	.355	.0	.00738	86.01	1543.16	218.94	2851.60
87.000	24000.0	99000.0	24000.0	.431	.439	.0	.00912	87.01	1585.02	218.60	2851.60
88.000	24000.0	99000.0	24000.0	.556	.565	.0	.01176	88.01	1656.52	218.14	2851.60
89.200	24000.0	99000.0	24000.0	.818	.830	.0	.01727	89.22	1826.64	217.39	2851.60
89.400	24000.0	99000.0	24000.0	.882	.894	.0	.01862	89.42	1871.07	217.25	2851.60
89.600	24000.0	99000.0	24000.0	.955	.967	.0	.02014	89.62	1922.37	217.11	2851.60
89.800	24000.0	99000.0	24000.0	1.038	1.050	.0	.02187	89.82	1981.53	216.97	2851.60
90.000	24000.0	99000.0	24000.0	1.100	1.146	.0	.02385	90.02	2048.97	216.82	2809.97
90.200	24000.0	99000.0	23960.6	1.210	1.255	10.4	.02612	90.23	2132.69	216.68	2832.01
90.400	24000.0	99000.0	23842.6	1.337	1.382	21.5	.02876	90.43	2218.18	216.54	2891.55
90.600	24000.0	99000.0	23645.7	1.486	1.529	34.3	.03183	90.63	2325.79	216.40	2990.29
90.800	24000.0	99000.0	23370.0	1.661	1.702	49.4	.03542	90.84	2458.96	216.27	3132.48
91.000	24000.0	99000.0	23015.3	1.867	1.905	67.5	.03965	91.04	2604.31	216.15	3324.41
91.200	24000.0	99000.0	22581.5	2.115	2.147	89.6	.04467	91.24	2813.26	216.03	3575.96
91.400	24000.0	99000.0	22068.3	2.413	2.435	116.8	.05068	91.45	3048.74	215.92	3898.50
91.600	24000.0	99000.0	21475.4	2.777	2.783	151.0	.05792	91.66	3365.58	215.82	4310.05
91.800	24000.0	99000.0	20802.4	3.224	3.205	194.3	.06671	91.87	3689.58	215.73	4832.87
92.000	24000.0	99000.0	20048.8	3.781	3.722	249.8	.07748	92.08	4126.54	215.65	5499.42
92.200	24000.0	99000.0	19213.7	4.478	4.361	321.6	.09079	92.29	4710.15	215.57	6357.30
92.400	24000.0	99000.0	18296.7	5.368	5.153	412.9	.10675	92.51	5352.74	215.71	7465.05
92.600	24000.0	99000.0	17296.1	6.525	6.148	533.9	.12696	92.73	6213.80	215.94	8919.94
92.800	24000.0	99000.0	16210.3	8.064	7.412	695.7	.15271	92.95	7370.15	216.25	10868.60
93.000	24000.0	99000.0	15036.7	10.164	9.037	914.8	.18587	93.19	8721.39	216.62	13541.61
93.200	24000.0	99000.0	13772.6	13.057	11.144	1194.5	.22585	93.43	10550.68	217.14	17261.08
93.400	24000.0	99000.0	12412.1	17.382	13.946	1622.8	.28446	93.68	13068.85	217.68	22839.78
93.600	24000.0	99000.0	10948.3	23.288	17.713	2201.1	.35910	93.96	16364.21	218.25	31247.37
93.800	24000.0	99000.0	9390.1	31.257	22.560	2816.5	.43193	94.23	20637.66	220.84	42835.68
94.000	24000.0	99000.0	7740.5	40.250	28.356	3158.3	.46730	94.47	26235.90	226.63	56359.11
94.200	24000.0	99000.0	5956.4	58.464	36.396	4404.8	.60348	94.80	33054.25	233.38	83689.61

UNREFRACTED RAY STRIKES OISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	25000.0	99000.0	25000.0	.148	.151	.0	.00310	81.00	1257.73	220.43	2433.04
82.000	25000.0	99000.0	25000.0	.165	.168	.0	.00347	82.00	1262.94	220.35	2433.04
83.000	25000.0	99000.0	25000.0	.186	.190	.0	.00392	83.00	1270.06	220.25	2433.04
84.000	25000.0	99000.0	25000.0	.213	.217	.0	.00450	84.00	1280.09	220.11	2433.04
85.000	25000.0	99000.0	25000.0	.248	.254	.0	.00526	85.01	1294.73	219.91	2433.04
86.000	25000.0	99000.0	25000.0	.297	.304	.0	.00630	86.01	1317.03	219.64	2433.04
87.000	25000.0	99000.0	25000.0	.367	.375	.0	.00779	87.01	1352.81	219.26	2433.04
88.000	25000.0	99000.0	25000.0	.474	.483	.0	.01005	88.01	1413.86	218.73	2433.04
89.200	25000.0	99000.0	25000.0	.697	.708	.0	.01475	89.21	1558.97	217.86	2433.04
89.400	25000.0	99000.0	25000.0	.752	.763	.0	.01590	89.42	1596.86	217.69	2433.04
89.600	25000.0	99000.0	25000.0	.814	.826	.0	.01720	89.62	1640.60	217.52	2433.04
89.800	25000.0	99000.0	25000.0	.884	.897	.0	.01867	89.82	1691.03	217.34	2433.04
90.000	25000.0	99000.0	25000.0	.935	.978	.4	.02036	90.02	1748.51	217.17	2394.51
90.200	25000.0	99000.0	24960.7	1.028	1.071	8.8	.02230	90.22	1819.86	216.99	2412.71
90.400	25000.0	99000.0	24842.8	1.136	1.179	18.3	.02455	90.42	1892.73	216.82	2462.76
90.600	25000.0	99000.0	24646.2	1.262	1.305	29.2	.02716	90.63	1984.45	216.66	2546.00
90.800	25000.0	99000.0	24370.9	1.410	1.452	42.0	.03022	90.83	2097.95	216.50	2665.97
91.000	25000.0	99000.0	24016.8	1.585	1.625	57.4	.03383	91.03	2221.84	216.34	2827.89
91.200	25000.0	99000.0	23583.7	1.795	1.831	76.2	.03811	91.24	2399.88	216.20	3039.98
91.400	25000.0	99000.0	23071.5	2.046	2.077	99.3	.04322	91.44	2600.50	216.07	3311.60
91.600	25000.0	99000.0	22479.8	2.352	2.372	126.3	.04937	91.65	2870.19	215.95	3657.61
91.800	25000.0	99000.0	21808.4	2.728	2.731	165.0	.05684	91.86	3146.22	215.84	4096.15
92.000	25000.0	99000.0	21056.7	3.194	3.170	212.0	.06598	92.07	3518.13	215.74	4653.52
92.200	25000.0	99000.0	20224.1	3.780	3.712	272.7	.07728	92.28	4014.00	215.65	5366.62
92.400	25000.0	99000.0	19309.9	4.529	4.388	352.1	.09136	92.49	4562.40	215.57	6289.74
92.600	25000.0	99000.0	18313.2	5.482	5.234	454.0	.10842	92.71	5295.95	215.70	7494.16
92.800	25000.0	99000.0	17232.3	6.747	6.306	590.5	.13026	92.93	6278.47	215.94	9092.87
93.000	25000.0	99000.0	16065.2	8.452	7.680	774.9	.15834	93.16	7429.60	216.26	11260.91
93.200	25000.0	99000.0	14809.6	10.779	9.459	1010.9	.19234	93.39	8984.35	216.72	14248.40
93.400	25000.0	99000.0	13460.6	14.189	11.810	1369.0	.24133	93.64	11113.29	217.25	18621.07
93.600	25000.0	99000.0	12012.4	19.304	14.962	1859.6	.30578	93.91	13735.37	217.79	25225.54
93.800	25000.0	99000.0	10457.7	26.147	19.253	2551.7	.39103	94.19	17596.27	218.51	35392.65
94.000	25000.0	99000.0	8817.3	33.745	24.397	2770.5	.41317	94.41	22262.23	222.40	46125.27
94.200	25000.0	99000.0	7054.9	50.012	31.647	4236.1	.57440	94.77	28751.62	228.79	71114.38

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## LATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	M(N. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(IEFF) (10)	T(IEFF) (11)	P(TAN) (12)
81.000	26000.0	99000.0	26000.0	.126	.129	.0	.00265	81.00	1073.35	221.35	2075.92
82.000	26000.0	99000.0	26000.0	.140	.144	.0	.00296	82.00	1077.82	221.27	2075.92
83.000	26000.0	99000.0	26000.0	.158	.162	.0	.00335	83.00	1083.93	221.15	2075.92
84.000	26000.0	99000.0	26000.0	.181	.186	.0	.00384	84.00	1092.52	221.00	2075.92
85.000	26000.0	99000.0	26000.0	.212	.217	.0	.00449	85.00	1105.05	220.79	2075.92
86.000	26000.0	99000.0	26000.0	.253	.259	.0	.00538	86.01	1124.13	220.49	2075.92
87.000	26000.0	99000.0	26000.0	.313	.320	.0	.00666	87.01	1154.71	220.06	2075.92
88.000	26000.0	99000.0	26000.0	.404	.412	.0	.00859	88.01	1206.85	219.45	2075.92
89.200	26000.0	99000.0	26000.0	.594	.605	.0	.01261	89.21	1330.65	218.42	2075.92
89.400	26000.0	99000.0	26000.0	.641	.652	.0	.01358	89.41	1362.96	218.22	2075.92
89.600	26000.0	99000.0	26000.0	.693	.705	.0	.01469	89.61	1400.25	218.02	2075.92
89.800	26000.0	99000.0	26000.0	.754	.765	.0	.01595	89.82	1443.24	217.81	2075.92
90.000	26000.0	99000.0	26000.0	.794	.835	.3	.01739	90.02	1492.24	217.59	2040.38
90.200	26000.0	99000.0	25960.7	.874	.914	7.5	.01905	90.22	1553.05	217.38	2055.48
90.400	26000.0	99000.0	25843.0	.966	1.007	15.5	.02096	90.42	1615.16	217.17	2097.63
90.600	26000.0	99000.0	25646.6	1.073	1.114	24.8	.02319	90.62	1693.34	216.97	2167.92
90.800	26000.0	99000.0	25371.7	1.198	1.239	35.8	.02580	90.83	1790.09	216.77	2269.29
91.000	26000.0	99000.0	25018.1	1.347	1.387	48.9	.02887	91.03	1895.69	216.59	2406.09
91.200	26000.0	99000.0	24585.6	1.524	1.562	64.8	.03251	91.23	2047.41	216.41	2585.21
91.400	26000.0	99000.0	24074.2	1.736	1.771	84.5	.03686	91.44	2218.36	216.25	2814.34
91.600	26000.0	99000.0	23483.5	1.994	2.023	109.1	.04210	91.64	2447.98	216.10	3105.86
91.800	26000.0	99000.0	22813.4	2.310	2.328	140.3	.04845	91.85	2683.21	215.97	3473.61
92.000	26000.0	99000.0	22063.3	2.702	2.702	180.1	.05622	92.06	2999.84	215.85	3942.03
92.200	26000.0	99000.0	21232.8	3.192	3.162	231.5	.06581	92.27	3421.41	215.74	4538.04
92.400	26000.0	99000.0	20321.3	3.816	3.735	298.6	.07775	92.48	3888.25	215.65	5306.29
92.600	26000.0	99000.0	19327.6	4.616	4.456	387.2	.09277	92.69	4513.29	215.57	6308.89
92.800	26000.0	99000.0	18250.9	5.659	5.367	502.1	.11121	92.91	5283.99	215.70	7626.03
93.000	26000.0	99000.0	17089.3	7.057	6.532	657.6	.13501	93.14	6329.65	215.95	9400.98
93.200	26000.0	99000.0	15840.7	8.955	8.037	857.3	.16398	93.36	7651.86	216.34	11820.04
93.400	26000.0	99000.0	14501.4	11.657	10.016	1153.1	.20507	93.61	9342.07	216.85	15294.46
93.600	26000.0	99000.0	13066.3	15.638	12.658	1563.9	.25921	93.86	11681.44	217.35	20429.40
93.800	26000.0	99000.0	11529.5	21.475	16.232	2133.2	.33013	94.13	14760.11	218.04	28329.89
94.000	26000.0	99000.0	9886.3	28.580	20.966	2578.8	.38236	94.38	19047.30	219.07	38578.84
94.200	26000.0	99000.0	8147.0	41.190	27.196	3716.5	.50772	94.71	24667.76	224.62	57516.32
94.400	26000.0	99000.0	6300.0	58.464	35.007	4734.9	.61084	95.01	31870.60	232.33	83545.17

UNREFRACTED RAY STRIKES OISC



# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	27000.0	99000.0	27000.0	.107	.110	.0	.00226	81.00	916.07	222.44	1771.21
82.000	27000.0	99000.0	27000.0	.120	.123	.0	.00253	82.00	919.91	222.34	1771.21
83.000	27000.0	99000.0	27000.0	.135	.139	.0	.00286	83.00	925.14	222.22	1771.21
84.000	27000.0	99000.0	27000.0	.155	.159	.0	.00328	84.00	932.50	222.05	1771.21
85.000	27000.0	99000.0	27000.0	.181	.185	.0	.00384	85.00	943.24	221.82	1771.21
86.000	27000.0	99000.0	27000.0	.216	.221	.0	.00460	86.00	959.57	221.49	1771.21
87.000	27000.0	99000.0	27000.0	.267	.273	.0	.00569	87.01	985.72	221.01	1771.21
88.000	27000.0	99000.0	27000.0	.345	.352	.0	.00734	88.01	1030.25	220.33	1771.21
89.200	27000.0	99000.0	27000.0	.507	.516	.0	.01077	89.21	1135.88	219.13	1771.21
89.400	27000.0	99000.0	27000.0	.546	.556	.0	.01161	89.41	1163.44	218.89	1771.21
89.600	27000.0	99000.0	27000.0	.591	.602	.0	.01256	89.61	1195.23	218.64	1771.21
89.800	27000.0	99000.0	27000.0	.642	.653	.0	.01363	89.81	1231.88	218.39	1771.21
90.000	27000.0	99000.0	27000.0	.675	.712	.2	.01486	90.01	1273.65	218.13	1738.55
90.200	27000.0	99000.0	26960.8	.743	.780	6.3	.01627	90.22	1325.49	217.87	1751.11
90.400	27000.0	99000.0	26843.1	.821	.859	13.2	.01791	90.42	1378.42	217.61	1786.68
90.600	27000.0	99000.0	26647.0	.912	.951	21.1	.01981	90.62	1445.06	217.36	1846.11
90.800	27000.0	99000.0	26372.3	1.018	1.058	30.5	.02203	90.82	1527.53	217.12	1931.87
91.000	27000.0	99000.0	26019.1	1.144	1.184	41.6	.02465	91.02	1617.54	216.89	2047.59
91.200	27000.0	99000.0	25587.2	1.294	1.333	55.2	.02775	91.23	1746.86	216.67	2199.07
91.400	27000.0	99000.0	25076.4	1.474	1.511	72.0	.03146	91.43	1892.54	216.48	2392.67
91.600	27000.0	99000.0	24486.6	1.692	1.726	92.9	.03591	91.64	2088.11	216.29	2638.69
91.800	27000.0	99000.0	23817.5	1.958	1.986	119.3	.04132	91.84	2288.58	216.13	2948.50
92.000	27000.0	99000.0	23068.9	2.288	2.303	153.1	.04793	92.05	2558.24	215.98	3342.34
92.200	27000.0	99000.0	22240.1	2.699	2.695	196.7	.05607	92.26	2916.82	215.85	3841.99
92.400	27000.0	99000.0	21330.8	3.221	3.181	253.5	.06621	92.47	3314.36	215.74	4483.69
92.600	27000.0	99000.0	20340.0	3.890	3.793	328.4	.07894	92.68	3845.88	215.64	5315.61
92.800	27000.0	99000.0	19266.6	4.759	4.569	428.1	.09511	92.90	4502.79	215.56	6411.50
93.000	27000.0	99000.0	18109.6	5.910	5.558	559.0	.11523	93.12	5392.72	215.70	7870.39
93.200	27000.0	99000.0	16867.0	7.463	6.834	728.3	.13992	93.34	6517.72	216.01	9847.37
93.400	27000.0	99000.0	15535.7	9.635	8.505	975.6	.17448	93.57	7955.24	216.47	12637.24
93.600	27000.0	99000.0	14111.5	12.781	10.727	1319.2	.22012	93.82	9938.51	216.94	16690.87
93.800	27000.0	99000.0	12589.5	17.514	13.717	1790.3	.27938	94.08	12545.59	217.59	22804.76
94.000	27000.0	99000.0	10959.5	24.609	17.845	2482.6	.36211	94.36	16215.72	218.22	32524.79
94.200	27000.0	99000.0	9228.9	33.671	23.300	3274.6	.44981	94.65	21094.02	221.07	46743.68
94.400	27000.0	99000.0	7400.9	47.550	30.133	4132.7	.53781	94.94	27391.40	227.81	67065.73
94.600	27000.0	99000.0	5450.6	70.040	39.150	5357.5	.65798	95.26	35969.03	236.24	100618.43

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/50 M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN A(R MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	28000.0	99000.0	28000.0	.092	.094	.0	.00193	81.00	781.91	223.72	1511.24
82.000	28000.0	99000.0	28000.0	.102	.105	.0	.00216	82.00	785.20	223.62	1511.24
83.000	28000.0	99000.0	28000.0	.115	.118	.0	.00244	83.00	789.69	223.49	1511.24
84.000	28000.0	99000.0	28000.0	.132	.135	.0	.00280	84.00	796.00	223.31	1511.24
85.000	28000.0	99000.0	28000.0	.154	.158	.0	.00328	85.00	805.20	223.05	1511.24
86.000	28000.0	99000.0	28000.0	.184	.189	.0	.00393	86.00	819.19	222.69	1511.24
87.000	28000.0	99000.0	28000.0	.228	.233	.0	.00486	87.00	841.55	222.17	1511.24
88.000	28000.0	99000.0	28000.0	.294	.300	.0	.00627	88.01	879.60	221.40	1511.24
89.200	28000.0	99000.0	28000.0	.432	.441	.0	.00922	89.21	969.73	220.02	1511.24
89.400	28000.0	99000.0	28000.0	.466	.475	.0	.00993	89.41	993.23	219.74	1511.24
89.600	28000.0	99000.0	28000.0	.504	.513	.0	.01074	89.61	1020.34	219.44	1511.24
89.800	28000.0	99000.0	28000.0	.548	.558	.0	.01166	89.81	1051.60	219.13	1511.24
90.000	28000.0	99000.0	28000.0	.574	.608	.2	.01271	90.01	1087.20	218.81	1481.31
90.200	28000.0	99000.0	27960.8	.631	.666	5.4	.01391	90.21	1131.40	218.49	1491.79
90.400	28000.0	99000.0	27843.3	.698	.733	11.3	.01531	90.42	1176.51	218.17	1521.84
90.600	28000.0	99000.0	27647.3	.775	.811	18.0	.01693	90.62	1233.32	217.86	1571.61
90.800	28000.0	99000.0	27372.9	.866	.903	26.0	.01882	90.82	1303.62	217.55	1644.78
91.000	28000.0	99000.0	27020.0	.972	1.010	35.5	.02105	91.02	1380.34	217.27	1742.78
91.200	28000.0	99000.0	26588.5	1.100	1.138	47.0	.02369	91.22	1490.56	217.00	1871.02
91.400	28000.0	99000.0	26078.2	1.252	1.290	61.3	.02685	91.43	1614.73	216.75	2034.81
91.600	28000.0	99000.0	25489.2	1.436	1.472	79.1	.03065	91.63	1781.33	216.53	2242.04
91.800	28000.0	99000.0	24821.0	1.661	1.694	101.6	.03525	91.84	1952.19	216.33	2504.19
92.000	28000.0	99000.0	24073.5	1.939	1.964	130.3	.04087	92.04	2181.90	216.15	2835.18
92.200	28000.0	99000.0	23246.2	2.285	2.297	167.3	.04780	92.25	2487.04	215.99	3255.93
92.400	28000.0	99000.0	22338.7	2.722	2.711	215.5	.05641	92.46	2825.65	215.85	3793.59
92.600	28000.0	99000.0	21350.3	3.281	3.230	278.8	.06722	92.67	3277.86	215.73	4487.77
92.800	28000.0	99000.0	20280.1	4.008	3.888	363.1	.08092	92.88	3836.66	215.63	5397.34
93.000	28000.0	99000.0	19126.7	4.964	4.731	476.4	.09849	93.10	4594.39	215.54	6606.95
93.200	28000.0	99000.0	17889.1	6.240	5.815	619.6	.11949	93.32	5552.04	215.74	8229.66
93.400	28000.0	99000.0	16564.6	8.003	7.229	827.1	.14861	93.55	6775.32	216.14	10492.05
93.600	28000.0	99000.0	15149.4	10.532	9.103	1115.6	.18720	93.79	8458.22	216.56	13730.19
93.800	28000.0	99000.0	13639.7	14.241	11.615	1507.4	.23688	94.04	10668.31	217.17	18511.69
94.000	28000.0	99000.0	12026.9	19.857	15.066	2096.0	.30795	94.31	13607.38	217.76	26121.90
94.200	28000.0	99000.0	10301.7	28.434	19.882	2940.7	.40725	94.60	17785.90	218.54	38282.76
94.400	28000.0	99000.0	8490.5	38.844	25.872	3610.7	.47333	94.87	23465.36	223.77	54159.44
94.600	28000.0	99000.0	6561.9	55.907	33.738	4636.8	.57558	95.18	30656.51	231.38	79806.73

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (IEFF) (10)	T (IEFF) (11)	P (TAN) (12)
81.000	29000.0	99000.0	29000.0	.078	.080	.0	.00165	81.00	667.47	225.22	1289.42
82.000	29000.0	99000.0	29000.0	.087	.090	.0	.00185	82.00	670.30	225.12	1289.42
83.000	29000.0	99000.0	29000.0	.098	.101	.0	.00209	83.00	674.15	224.98	1289.42
84.000	29000.0	99000.0	29000.0	.113	.116	.0	.00240	84.00	679.56	224.79	1289.42
85.000	29000.0	99000.0	29000.0	.132	.135	.0	.00280	85.00	687.45	224.52	1289.42
86.000	29000.0	99000.0	29000.0	.157	.161	.0	.00336	86.00	699.42	224.13	1289.42
87.000	29000.0	99000.0	29000.0	.194	.199	.0	.00415	87.00	718.55	223.57	1289.42
88.000	29000.0	99000.0	29000.0	.251	.256	.0	.00536	88.01	751.05	222.72	1289.42
89.200	29000.0	99000.0	29000.0	.369	.376	.0	.00789	89.21	827.94	221.18	1289.42
89.400	29000.0	99000.0	29000.0	.397	.405	.0	.00851	89.41	847.98	220.85	1289.42
89.600	29000.0	99000.0	29000.0	.430	.438	.0	.00921	89.61	871.11	220.49	1289.42
89.800	29000.0	99000.0	29000.0	.467	.476	.0	.01000	89.81	897.76	220.12	1289.42
90.000	29000.0	99000.0	29000.0	.488	.519	.1	.01090	90.01	928.13	219.72	1262.06
90.200	29000.0	99000.0	28960.8	.537	.568	4.6	.01192	90.21	965.82	219.31	1270.84
90.400	29000.0	99000.0	28843.4	.593	.626	9.6	.01311	90.41	1004.28	218.90	1296.26
90.600	29000.0	99000.0	28647.5	.659	.692	15.4	.01448	90.61	1052.72	218.50	1338.41
90.800	29000.0	99000.0	28373.3	.736	.770	22.2	.01609	90.82	1112.65	218.12	1400.46
91.000	29000.0	99000.0	28020.7	.827	.862	30.3	.01799	91.02	1178.05	217.75	1483.52
91.200	29000.0	99000.0	27589.5	.935	.971	40.1	.02024	91.22	1272.00	217.41	1592.20
91.400	29000.0	99000.0	27079.8	1.064	1.101	52.3	.02293	91.42	1377.84	217.10	1730.91
91.600	29000.0	99000.0	26491.3	1.220	1.256	67.4	.02616	91.63	1519.78	216.82	1906.26
91.800	29000.0	99000.0	25823.9	1.410	1.445	86.5	.03008	91.83	1665.43	216.57	2127.84
92.000	29000.0	99000.0	25077.3	1.645	1.676	110.9	.03487	92.03	1861.14	216.35	2407.16
92.200	29000.0	99000.0	24251.3	1.937	1.959	142.4	.04076	92.24	2094.45	216.16	2761.55
92.400	29000.0	99000.0	23345.4	2.304	2.311	183.2	.04808	92.45	2409.38	215.99	3213.21
92.600	29000.0	99000.0	22359.0	2.772	2.752	237.0	.05727	92.66	2794.27	215.84	3794.34
92.800	29000.0	99000.0	21291.4	3.377	3.311	308.3	.06890	92.87	3269.81	215.72	4551.20
93.000	29000.0	99000.0	20141.4	4.174	4.025	403.9	.08378	93.08	3913.64	215.61	5553.41
93.200	29000.0	99000.0	18907.7	5.233	4.949	528.2	.10216	93.30	4729.49	215.55	6898.13
93.400	29000.0	99000.0	17588.9	6.676	6.148	702.4	.12671	93.53	5770.97	215.86	8746.92
93.600	29000.0	99000.0	16181.3	8.717	7.733	945.4	.15939	93.76	7200.09	216.21	11357.75
93.800	29000.0	99000.0	14681.9	11.661	9.850	1272.3	.20113	94.00	9075.35	216.77	15148.51
94.000	29000.0	99000.0	13083.4	16.210	12.742	1763.3	.26095	94.26	11567.89	217.33	21021.15
94.200	29000.0	99000.0	11378.5	22.910	16.748	2458.5	.34110	94.54	15093.03	218.07	30461.12
94.400	29000.0	99000.0	9570.2	32.235	22.138	3167.4	.41750	94.82	19839.11	220.43	43876.99
94.600	29000.0	99000.0	7660.9	45.122	29.004	3983.1	.49989	95.10	26321.00	226.90	63571.39
94.800	29000.0	99000.0	5626.9	68.074	38.182	5300.9	.62716	95.43	34934.60	235.49	97718.80

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	30000.0	99000.0	30000.0	.067	.069	.0	.00140	81.00	569.98	226.99	1100.16
82.000	30000.0	99000.0	30000.0	.074	.077	.0	.00156	82.00	572.40	226.89	1100.16
83.000	30000.0	99000.0	30000.0	.084	.086	.0	.00176	83.00	575.71	226.74	1100.16
84.000	30000.0	99000.0	30000.0	.096	.099	.0	.00203	84.00	580.36	226.54	1100.16
85.000	30000.0	99000.0	30000.0	.112	.115	.0	.00237	85.00	587.12	226.26	1100.16
86.000	30000.0	99000.0	30000.0	.134	.138	.0	.00284	86.00	597.37	225.86	1100.16
87.000	30000.0	99000.0	30000.0	.166	.170	.0	.00351	87.00	613.73	225.26	1100.16
88.000	30000.0	99000.0	30000.0	.214	.219	.0	.00452	88.00	641.48	224.37	1100.16
89.200	30000.0	99000.0	30000.0	.314	.320	.0	.00663	89.21	706.93	222.76	1100.16
89.400	30000.0	99000.0	30000.0	.339	.345	.0	.00714	89.41	723.95	222.44	1100.16
89.600	30000.0	99000.0	30000.0	.367	.373	.0	.00772	89.61	743.58	222.10	1100.16
89.800	30000.0	99000.0	30000.0	.398	.405	.0	.00837	89.81	766.19	221.75	1100.16
90.000	30000.0	99000.0	30000.0	.409	.441	.1	.00912	90.01	791.94	221.40	1075.68
90.200	30000.0	99000.0	29960.8	.450	.483	4.0	.01041	90.21	823.99	220.84	1082.98
90.400	30000.0	99000.0	29843.3	.505	.533	8.6	.01188	90.41	856.94	220.16	1104.20
90.600	30000.0	99000.0	29647.5	.560	.590	13.4	.01283	90.61	898.50	219.43	1139.94
90.800	30000.0	99000.0	29373.4	.626	.657	19.1	.01401	90.81	949.70	218.89	1192.57
91.000	30000.0	99000.0	29021.0	.703	.736	25.9	.01555	91.02	1005.50	218.39	1263.02
91.200	30000.0	99000.0	28590.2	.795	.828	34.3	.01743	91.22	1085.63	217.95	1355.20
91.400	30000.0	99000.0	28080.8	.904	.939	44.6	.01969	91.42	1175.86	217.55	1472.79
91.600	30000.0	99000.0	27492.8	1.037	1.072	57.5	.02243	91.62	1296.83	217.19	1621.32
91.800	30000.0	99000.0	26826.0	1.198	1.233	73.8	.02576	91.83	1420.99	216.88	1808.84
92.000	30000.0	99000.0	26080.3	1.396	1.430	94.5	.02982	92.03	1587.78	216.60	2044.92
92.200	30000.0	99000.0	25235.3	1.643	1.671	121.3	.03484	92.23	1786.59	216.36	2343.96
92.400	30000.0	99000.0	24350.6	1.951	1.971	156.0	.04106	92.44	2058.81	216.15	2723.40
92.600	30000.0	99000.0	23365.9	2.344	2.346	201.6	.04886	92.65	2382.52	215.98	3211.14
92.800	30000.0	99000.0	22300.5	2.851	2.821	262.0	.05874	92.86	2787.37	215.83	3845.00
93.000	30000.0	99000.0	21153.4	3.515	3.427	343.0	.07137	93.07	3334.77	215.70	4678.90
93.200	30000.0	99000.0	19923.4	4.399	4.211	452.6	.08769	93.29	4028.37	215.59	5795.02
93.400	30000.0	99000.0	18609.1	5.593	5.232	597.6	.10819	93.51	4915.88	215.65	7313.85
93.600	30000.0	99000.0	17207.9	7.250	6.575	802.7	.13590	93.74	6130.36	215.91	9440.33
93.800	30000.0	99000.0	15717.0	9.611	8.364	1075.9	.17099	93.97	7722.80	216.40	12477.62
94.000	30000.0	99000.0	14130.5	13.187	10.796	1488.0	.22158	94.22	9838.71	216.92	17088.72
94.200	30000.0	99000.0	12442.3	18.809	14.146	2064.0	.28860	94.49	12816.74	217.63	24353.31
94.400	30000.0	99000.0	10640.6	27.025	18.876	2915.4	.38262	94.78	16906.33	218.41	36327.92
94.600	30000.0	99000.0	8748.4	36.141	24.789	3248.1	.41592	95.02	22496.86	222.90	49741.93
94.800	30000.0	99000.0	6736.8	53.294	32.793	4384.1	.52862	95.33	30009.78	230.59	75519.96

UNREFRACTED RAY STRIKES OISC



# REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
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IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	31000.0	99000.0	31000.0	.057	.059	.0	.00120	81.00	487.55	228.67	940.37
82.000	31000.0	99000.0	31000.0	.064	.066	.0	.00134	82.00	489.63	228.56	940.37
83.000	31000.0	99000.0	31000.0	.072	.074	.0	.00151	83.00	492.48	228.41	940.37
84.000	31000.0	99000.0	31000.0	.082	.085	.0	.00173	84.00	496.48	228.20	940.37
85.000	31000.0	99000.0	31000.0	.096	.099	.0	.00203	85.00	502.29	227.90	940.37
86.000	31000.0	99000.0	31000.0	.115	.118	.0	.00243	86.00	511.09	227.46	940.37
87.000	31000.0	99000.0	31000.0	.142	.145	.0	.00300	87.00	525.12	226.81	940.37
88.000	31000.0	99000.0	31000.0	.182	.187	.0	.00387	88.00	548.87	225.82	940.37
89.200	31000.0	99000.0	31000.0	.268	.274	.0	.00568	89.21	604.81	223.97	940.37
89.400	31000.0	99000.0	31000.0	.288	.295	.0	.00612	89.41	619.35	223.58	940.37
89.600	31000.0	99000.0	31000.0	.312	.319	.0	.00661	89.61	636.11	223.17	940.37
89.800	31000.0	99000.0	31000.0	.339	.347	.0	.00718	89.81	655.41	222.75	940.37
90.000	31000.0	99000.0	31000.0	.352	.360	.1	.00782	90.01	677.38	222.32	917.87
90.200	31000.0	99000.0	30960.9	.387	.413	3.3	.00855	90.21	704.63	221.88	924.00
90.400	31000.0	99000.0	30843.5	.427	.455	6.9	.00940	90.41	732.44	221.45	942.09
90.600	31000.0	99000.0	30647.9	.474	.503	11.0	.01039	90.61	767.44	221.03	972.13
90.800	31000.0	99000.0	30374.0	.529	.559	15.8	.01154	90.81	810.71	220.62	1016.04
91.000	31000.0	99000.0	30021.8	.594	.625	21.6	.01289	91.01	857.91	220.23	1075.63
91.200	31000.0	99000.0	29590.9	.677	.705	29.9	.01513	91.22	926.46	219.03	1153.65
91.400	31000.0	99000.0	29081.9	.770	.801	38.3	.01689	91.42	1003.56	218.36	1253.33
91.600	31000.0	99000.0	28494.3	.882	.914	49.2	.01919	91.62	1106.75	217.83	1379.24
91.800	31000.0	99000.0	27828.1	1.019	1.052	63.0	.02201	91.82	1212.63	217.39	1538.09
92.000	31000.0	99000.0	27083.0	1.187	1.219	80.6	.02546	92.03	1354.80	217.01	1737.85
92.200	31000.0	99000.0	26258.8	1.394	1.425	103.3	.02973	92.23	1524.26	216.69	1989.90
92.400	31000.0	99000.0	25355.3	1.655	1.681	132.9	.03503	92.44	1752.75	216.41	2310.56
92.600	31000.0	99000.0	24372.0	1.986	2.000	171.6	.04166	92.64	2031.86	216.18	2720.91
92.800	31000.0	99000.0	23308.4	2.411	2.404	222.8	.05006	92.85	2376.62	215.99	3252.53
93.000	31000.0	99000.0	22163.7	2.965	2.919	291.4	.06078	93.06	2842.26	215.83	3948.92
93.200	31000.0	99000.0	20936.8	3.700	3.584	384.2	.07462	93.27	3431.94	215.69	4875.65
93.400	31000.0	99000.0	19626.3	4.695	4.452	511.1	.09270	93.49	4187.36	215.58	6134.47
93.600	31000.0	99000.0	18230.5	6.052	5.593	682.6	.11595	93.72	5220.11	215.69	7873.73
93.800	31000.0	99000.0	16746.8	7.963	7.108	910.0	.14529	93.95	6573.15	216.08	10329.42
94.000	31000.0	99000.0	15170.2	10.812	9.159	1258.7	.18839	94.19	8370.79	216.55	13998.95
94.200	31000.0	99000.0	13495.9	15.174	11.971	1738.5	.24466	94.44	10889.41	217.21	19630.52
94.400	31000.0	99000.0	11714.0	22.019	15.912	2436.3	.32466	94.72	14342.00	217.94	28842.92
94.600	31000.0	99000.0	9821.6	30.210	21.272	2949.1	.37727	94.98	19033.46	219.44	41074.84
94.800	31000.0	99000.0	7828.1	43.329	28.265	3833.6	.46595	95.27	25526.41	225.81	60993.98
95.000	31000.0	99000.0	5715.3	67.040	37.648	5262.8	.60091	95.60	34545.26	235.04	96179.51

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	32000.0	99000.0	32000.0	.049	.050	.0	.00102	81.00	417.15	230.65	803.63
82.000	32000.0	99000.0	32000.0	.054	.056	.0	.00114	82.00	418.95	230.53	803.63
83.000	32000.0	99000.0	32000.0	.061	.063	.0	.00129	83.00	421.40	230.37	803.63
84.000	32000.0	99000.0	32000.0	.070	.072	.0	.00148	84.00	424.84	230.15	803.63
85.000	32000.0	99000.0	32000.0	.082	.084	.0	.00174	85.00	429.83	229.84	803.63
86.000	32000.0	99000.0	32000.0	.098	.101	.0	.00208	86.00	437.39	229.39	803.63
87.000	32000.0	99000.0	32000.0	.121	.124	.0	.00257	87.00	449.43	228.70	803.63
88.000	32000.0	99000.0	32000.0	.156	.160	.0	.00332	88.00	469.77	227.62	803.63
89.200	32000.0	99000.0	32000.0	.229	.234	.0	.00487	89.20	517.59	225.50	803.63
89.400	32000.0	99000.0	32000.0	.246	.252	.0	.00525	89.41	530.01	225.04	803.63
89.600	32000.0	99000.0	32000.0	.266	.272	.0	.00568	89.61	544.32	224.55	803.63
89.800	32000.0	99000.0	32000.0	.289	.296	.0	.00616	89.81	560.79	224.03	803.63
90.000	32000.0	99000.0	32000.0	.299	.322	.0	.00671	90.01	579.54	223.50	783.18
90.200	32000.0	99000.0	31960.9	.329	.353	2.8	.00734	90.21	602.80	222.96	788.35
90.400	32000.0	99000.0	31843.6	.364	.388	5.9	.00806	90.41	626.53	222.41	803.72
90.600	32000.0	99000.0	31648.0	.404	.430	9.4	.00890	90.61	656.39	221.88	829.26
90.800	32000.0	99000.0	31374.2	.451	.478	13.6	.00989	90.81	693.31	221.37	866.62
91.000	32000.0	99000.0	31022.2	.506	.534	18.5	.01104	91.01	733.60	220.88	917.33
91.200	32000.0	99000.0	30591.8	.572	.601	24.5	.01241	91.21	791.38	220.42	983.19
91.400	32000.0	99000.0	30083.1	.650	.681	31.9	.01404	91.41	856.41	220.01	1067.05
91.600	32000.0	99000.0	29495.5	.750	.779	42.6	.01657	91.62	944.55	218.78	1173.62
91.800	32000.0	99000.0	28829.7	.866	.897	53.9	.01885	91.82	1034.94	218.08	1308.24
92.000	32000.0	99000.0	28085.2	1.008	1.040	68.9	.02176	92.02	1156.16	217.54	1477.44
92.200	32000.0	99000.0	27261.7	1.184	1.216	88.2	.02539	92.23	1300.61	217.10	1690.68
92.400	32000.0	99000.0	26359.1	1.404	1.434	113.2	.02989	92.43	1495.31	216.74	1961.55
92.600	32000.0	99000.0	25377.0	1.683	1.706	146.1	.03554	92.64	1733.07	216.44	2307.47
92.800	32000.0	99000.0	24314.9	2.041	2.050	189.7	.04268	92.84	2026.75	216.19	2754.42
93.000	32000.0	99000.0	23172.2	2.504	2.488	247.9	.05179	93.05	2423.00	215.98	3336.84
93.200	32000.0	99000.0	21948.0	3.118	3.053	326.4	.06355	93.26	2924.59	215.81	4110.36
93.400	32000.0	99000.0	20641.0	3.941	3.789	433.7	.07887	93.48	3566.98	215.68	5151.72
93.600	32000.0	99000.0	19249.5	5.069	4.759	582.2	.09912	93.70	4445.24	215.57	6589.27
93.800	32000.0	99000.0	17771.8	6.636	6.045	772.6	.12380	93.92	5531.67	215.81	8590.58
94.000	32000.0	99000.0	16203.6	8.929	7.780	1067.0	.16037	94.16	7123.84	216.21	11538.63
94.200	32000.0	99000.0	14540.8	12.370	10.148	1466.3	.20776	94.41	9155.35	216.81	15972.02
94.400	32000.0	99000.0	12775.2	17.819	13.446	2040.1	.27214	94.67	12038.10	217.49	23032.83
94.600	32000.0	99000.0	10894.9	26.142	18.159	2930.6	.36740	94.97	16223.44	218.24	35097.53
94.800	32000.0	99000.0	8909.5	36.953	24.382	3563.4	.43113	95.23	21897.88	221.73	50805.92
95.000	32000.0	99000.0	6818.7	53.362	32.436	4470.8	.51771	95.52	29428.34	229.88	75565.93

UNREFRACTED RAY STRIKES DISC



# REFRACTION AIRMASS TABLES

LATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	33000.0	99000.0	33000.0	.042	.043	.0	.00088	81.00	357.04	232.97	686.78
82.000	33000.0	99000.0	33000.0	.046	.048	.0	.00098	82.00	358.59	232.85	686.78
83.000	33000.0	99000.0	33000.0	.052	.054	.0	.00111	83.00	360.70	232.69	686.78
84.000	33000.0	99000.0	33000.0	.060	.062	.0	.00127	84.00	363.66	232.47	686.78
85.000	33000.0	99000.0	33000.0	.070	.072	.0	.00149	85.00	367.96	232.16	686.78
86.000	33000.0	99000.0	33000.0	.084	.086	.0	.00178	86.00	374.45	231.69	686.78
87.000	33000.0	99000.0	33000.0	.103	.106	.0	.00220	87.00	384.77	230.98	686.78
88.000	33000.0	99000.0	33000.0	.133	.136	.0	.00285	88.00	402.19	229.85	686.78
89.200	33000.0	99000.0	33000.0	.195	.200	.0	.00419	89.20	443.07	227.50	686.78
89.400	33000.0	99000.0	33000.0	.210	.215	.0	.00452	89.40	453.68	226.96	686.78
89.600	33000.0	99000.0	33000.0	.228	.232	.0	.00488	89.60	465.90	226.37	686.78
89.800	33000.0	99000.0	33000.0	.247	.252	.0	.00530	89.81	479.97	225.74	686.78
90.000	33000.0	99000.0	33000.0	.255	.275	.0	.00577	90.01	495.98	225.07	686.22
90.200	33000.0	99000.0	32960.9	.281	.301	2.4	.00631	90.21	515.82	224.38	672.59
90.400	33000.0	99000.0	32843.6	.310	.332	5.0	.00692	90.41	536.07	223.69	685.38
90.600	33000.0	99000.0	32648.1	.344	.367	8.1	.00764	90.61	561.55	223.00	707.39
90.800	33000.0	99000.0	32374.4	.384	.408	11.6	.00848	90.81	593.06	222.34	739.18
91.000	33000.0	99000.0	32022.5	.431	.457	15.8	.00946	91.01	627.43	221.71	782.36
91.200	33000.0	99000.0	31592.3	.487	.514	21.0	.01063	91.21	676.76	221.13	839.41
91.400	33000.0	99000.0	31083.7	.554	.582	27.3	.01202	91.41	732.27	220.60	909.76
91.600	33000.0	99000.0	30496.8	.633	.664	35.1	.01369	91.61	806.55	220.13	999.65
91.800	33000.0	99000.0	29831.1	.736	.763	48.1	.01665	91.82	883.11	219.37	1113.29
92.000	33000.0	99000.0	29087.0	.857	.887	59.1	.01866	92.02	986.73	218.27	1256.47
92.200	33000.0	99000.0	28264.1	1.006	1.037	75.3	.02170	92.22	1109.92	217.64	1437.03
92.400	33000.0	99000.0	27362.2	1.192	1.223	96.6	.02553	92.43	1275.85	217.15	1666.15
92.600	33000.0	99000.0	26381.1	1.428	1.455	124.6	.03033	92.63	1478.45	216.76	1958.23
92.800	33000.0	99000.0	25320.3	1.728	1.748	161.6	.03641	92.84	1728.66	216.44	2334.05
93.000	33000.0	99000.0	24179.2	2.118	2.121	211.0	.04416	93.04	2066.00	216.17	2823.92
93.200	33000.0	99000.0	22957.2	2.631	2.601	277.6	.05414	93.25	2492.83	215.96	3470.01
93.400	33000.0	99000.0	21653.2	3.317	3.226	368.4	.06715	93.47	3039.37	215.79	4337.26
93.600	33000.0	99000.0	20265.6	4.252	4.049	493.7	.08429	93.68	3740.96	215.65	5523.10
93.800	33000.0	99000.0	18792.7	5.546	5.143	658.4	.10577	93.91	4711.87	215.63	7172.90
94.000	33000.0	99000.0	17231.6	7.404	6.613	906.0	.13666	94.14	6063.91	215.92	9559.58
94.200	33000.0	99000.0	15578.4	10.150	8.613	1242.8	.17667	94.38	7792.19	216.45	13092.88
94.400	33000.0	99000.0	13826.3	14.420	11.387	1724.6	.23131	94.63	10237.78	217.05	18600.49
94.600	33000.0	99000.0	11965.6	21.329	15.322	2469.9	.31176	94.91	13767.12	217.77	27903.85
94.800	33000.0	99000.0	9982.8	31.596	20.962	3421.9	.40958	95.21	18725.39	218.65	42911.58
95.000	33000.0	99000.0	7909.3	44.786	28.076	4162.1	.47999	95.48	25318.28	225.24	62997.64
95.200	33000.0	99000.0	5715.7	69.064	37.673	5496.6	.60131	95.80	34517.58	235.02	99038.40

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	34000.0	99000.0	34000.0	.036	.037	.0	.00075	81.00	305.73	235.70	586.91
82.000	34000.0	99000.0	34000.0	.040	.041	.0	.00084	82.00	307.07	235.59	586.91
83.000	34000.0	99000.0	34000.0	.045	.046	.0	.00095	83.00	308.89	235.44	586.91
84.000	34000.0	99000.0	34000.0	.051	.053	.0	.00109	84.00	311.43	235.22	586.91
85.000	34000.0	99000.0	34000.0	.060	.062	.0	.00127	85.00	315.13	234.92	586.91
86.000	34000.0	99000.0	34000.0	.072	.074	.0	.00153	86.00	320.70	234.47	586.91
87.000	34000.0	99000.0	34000.0	.088	.091	.0	.00189	87.00	329.54	233.77	586.91
88.000	34000.0	99000.0	34000.0	.114	.116	.0	.00245	88.00	344.43	232.65	586.91
89.200	34000.0	99000.0	34000.0	.167	.170	.0	.00363	89.20	379.30	230.23	586.91
89.400	34000.0	99000.0	34000.0	.180	.183	.0	.00392	89.40	388.36	229.63	586.91
89.600	34000.0	99000.0	34000.0	.194	.198	.0	.00425	89.60	398.80	228.94	586.91
89.800	34000.0	99000.0	34000.0	.211	.215	.0	.00461	89.80	410.82	228.18	586.91
90.000	34000.0	99000.0	34000.0	.217	.234	.0	.00502	90.01	424.51	227.33	570.11
90.200	34000.0	99000.0	33960.9	.239	.257	2.1	.00547	90.21	441.48	226.41	573.80
90.400	34000.0	99000.0	33843.7	.264	.283	4.4	.00599	90.41	458.77	225.48	584.68
90.600	34000.0	99000.0	33648.2	.293	.313	7.0	.00659	90.61	480.53	224.55	603.42
90.800	34000.0	99000.0	33374.6	.327	.349	10.0	.00730	90.81	507.43	223.66	630.49
91.000	34000.0	99000.0	33022.7	.367	.390	13.6	.00813	91.01	536.75	222.82	667.26
91.200	34000.0	99000.0	32592.6	.415	.439	18.0	.00912	91.21	578.86	222.06	714.98
91.400	34000.0	99000.0	32084.2	.472	.497	23.4	.01030	91.41	626.24	221.37	775.72
91.600	34000.0	99000.0	31497.5	.540	.567	30.0	.01173	91.61	689.65	220.76	852.20
91.800	34000.0	99000.0	30832.3	.622	.652	38.5	.01345	91.81	754.76	220.22	948.44
92.000	34000.0	99000.0	30088.6	.723	.754	49.1	.01555	92.02	842.03	219.75	1069.01
92.200	34000.0	99000.0	29266.0	.854	.884	64.7	.01864	92.22	947.24	218.42	1221.91
92.400	34000.0	99000.0	28364.8	1.012	1.043	82.6	.02183	92.42	1088.75	217.70	1415.88
92.600	34000.0	99000.0	27384.4	1.212	1.241	106.3	.02590	92.63	1261.42	217.17	1662.83
92.800	34000.0	99000.0	26324.7	1.466	1.491	137.7	.03107	92.83	1474.63	216.75	1979.98
93.000	34000.0	99000.0	25185.0	1.794	1.809	179.7	.03766	93.04	1761.91	216.41	2392.32
93.200	34000.0	99000.0	23964.8	2.224	2.217	236.2	.04615	93.25	2125.28	216.14	2934.30
93.400	34000.0	99000.0	22663.3	2.797	2.748	313.2	.05720	93.46	2590.46	215.93	3658.46
93.600	34000.0	99000.0	21279.0	3.573	3.447	419.2	.07174	93.67	3187.51	215.76	4642.39
93.800	34000.0	99000.0	19810.3	4.650	4.376	566.9	.09111	93.89	4013.34	215.62	6009.44
94.000	34000.0	99000.0	18255.0	6.166	5.625	770.6	.11658	94.12	5101.28	215.70	7953.11
94.200	34000.0	99000.0	16609.9	8.379	7.318	1054.0	.15040	94.35	6633.54	216.13	10798.21
94.400	34000.0	99000.0	14869.1	11.758	9.658	1461.4	.19690	94.60	8709.93	216.65	15152.94
94.600	34000.0	99000.0	13024.8	17.303	12.958	2092.1	.26547	94.87	11558.49	217.34	22335.90
94.800	34000.0	99000.0	11065.2	26.178	17.708	3019.9	.36121	95.16	15718.33	218.16	34664.87
95.000	34000.0	99000.0	8991.1	38.466	24.265	4016.5	.45820	95.46	21722.72	221.37	53478.21
95.200	34000.0	99000.0	6819.7	54.809	32.458	4675.5	.51835	95.72	29404.20	229.86	77577.60

UNREFRACTED RAY STRIKES DISC



# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	MDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	35000.0	99000.0	35000.0	.030	.032	.0	.00061	81.00	262.20	238.90	501.57
82.000	35000.0	99000.0	35000.0	.034	.035	.0	.00068	82.00	263.36	238.80	501.57
83.000	35000.0	99000.0	35000.0	.038	.040	.0	.00077	83.00	264.92	238.66	501.57
84.000	35000.0	99000.0	35000.0	.044	.045	.0	.00088	84.00	267.11	238.47	501.57
85.000	35000.0	99000.0	35000.0	.051	.053	.0	.00103	85.00	270.29	238.19	501.57
86.000	35000.0	99000.0	35000.0	.061	.063	.0	.00124	86.00	275.07	237.78	501.57
87.000	35000.0	99000.0	35000.0	.075	.077	.0	.00153	87.00	282.63	237.16	501.57
88.000	35000.0	99000.0	35000.0	.097	.099	.0	.00196	88.00	295.31	236.19	501.57
89.200	35000.0	99000.0	35000.0	.143	.144	.0	.00286	89.20	324.73	234.36	501.57
89.400	35000.0	99000.0	35000.0	.154	.155	.0	.00307	89.40	332.31	233.98	501.57
89.600	35000.0	99000.0	35000.0	.166	.168	.0	.00332	89.60	341.03	233.58	501.57
89.800	35000.0	99000.0	35000.0	.180	.182	.0	.00359	89.80	351.04	233.16	501.57
90.000	35000.0	99000.0	35000.0	.172	.198	.0	.00390	90.00	362.43	232.74	487.49
90.200	35000.0	99000.0	34960.8	.191	.216	1.9	.00512	90.21	376.67	231.35	490.50
90.400	35000.0	99000.0	34843.3	.213	.239	4.5	.00652	90.41	391.74	229.34	499.42
90.600	35000.0	99000.0	34647.7	.250	.266	6.5	.00659	90.61	410.90	227.09	514.81
90.800	35000.0	99000.0	34374.1	.279	.297	8.9	.00679	90.81	434.11	225.66	537.85
91.000	35000.0	99000.0	34022.3	.313	.332	11.8	.00734	91.01	459.24	224.42	569.16
91.200	35000.0	99000.0	33592.3	.354	.375	15.5	.00810	91.21	495.25	223.34	609.56
91.400	35000.0	99000.0	33084.0	.402	.425	20.1	.00906	91.41	535.72	222.40	661.53
91.600	35000.0	99000.0	32497.5	.460	.485	25.8	.01024	91.61	589.88	221.59	726.64
91.800	35000.0	99000.0	31832.5	.530	.557	32.9	.01168	91.81	645.46	220.89	808.55
92.000	35000.0	99000.0	31089.1	.616	.645	42.1	.01346	92.01	719.98	220.29	911.10
92.200	35000.0	99000.0	30267.2	.722	.753	53.8	.01565	92.22	808.70	219.78	1039.80
92.400	35000.0	99000.0	29366.2	.860	.899	71.1	.02226	92.42	929.23	218.49	1203.83
92.600	35000.0	99000.0	28386.6	1.029	1.059	90.8	.02664	92.62	1076.50	217.71	1412.84
92.800	35000.0	99000.0	27327.7	1.244	1.272	117.5	.03224	92.83	1258.25	217.15	1680.87
93.000	35000.0	99000.0	26189.2	1.521	1.543	153.2	.03946	93.03	1502.98	216.71	2028.65
93.200	35000.0	99000.0	24970.6	1.882	1.891	201.2	.04884	93.24	1812.44	216.37	2484.42
93.400	35000.0	99000.0	23671.0	2.362	2.343	266.6	.06119	93.45	2208.53	216.10	3091.06
93.600	35000.0	99000.0	22289.5	3.008	2.936	356.4	.07600	93.66	2716.83	215.88	3909.84
93.800	35000.0	99000.0	20824.6	3.900	3.725	481.3	.09972	93.88	3419.06	215.72	5041.64
94.000	35000.0	99000.0	19274.1	5.154	4.786	657.2	.12826	94.10	4345.32	215.58	6642.13
94.200	35000.0	99000.0	17635.7	6.952	6.223	895.5	.16789	94.33	5648.50	215.86	8950.95
94.400	35000.0	99000.0	15904.4	9.658	8.202	1240.9	.22538	94.57	7412.79	216.29	12433.92
94.600	35000.0	99000.0	14073.8	13.981	10.976	1766.3	.30541	94.83	9830.46	216.94	18009.23
94.800	35000.0	99000.0	12134.1	21.018	14.942	2535.0	.42299	95.11	13345.17	217.72	27470.59
95.000	35000.0	99000.0	10068.5	32.602	20.777	3725.4	.48064	95.42	18348.29	218.60	44245.15
95.200	35000.0	99000.0	7910.1	45.929	28.097	4352.4		95.68	25297.99	225.23	64575.09

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	36000.0	99000.0	36000.0	.026	.027	.0	.00053	81.00	226.58	240.75	432.11
82.000	36000.0	99000.0	36000.0	.029	.030	.0	.00059	82.00	227.58	240.65	432.11
83.000	36000.0	99000.0	36000.0	.033	.034	.0	.00066	83.00	228.94	240.51	432.11
84.000	36000.0	99000.0	36000.0	.038	.039	.0	.00076	84.00	230.84	240.31	432.11
85.000	36000.0	99000.0	36000.0	.044	.045	.0	.00089	85.00	233.60	240.03	432.11
86.000	36000.0	99000.0	36000.0	.052	.054	.0	.00107	86.00	237.74	239.60	432.11
87.000	36000.0	99000.0	36000.0	.065	.067	.0	.00132	87.00	244.29	238.95	432.11
88.000	36000.0	99000.0	36000.0	.083	.085	.0	.00169	88.00	255.22	237.90	432.11
89.200	36000.0	99000.0	36000.0	.121	.124	.0	.00247	89.20	280.49	235.81	432.11
89.400	36000.0	99000.0	36000.0	.130	.134	.0	.00265	89.40	286.98	235.35	432.11
89.600	36000.0	99000.0	36000.0	.140	.144	.0	.00286	89.60	294.45	234.87	432.11
89.800	36000.0	99000.0	36000.0	.152	.156	.0	.00310	89.80	303.03	234.37	432.11
90.000	36000.0	99000.0	36000.0	.155	.170	.0	.00337	90.00	312.78	233.85	418.90
90.200	36000.0	99000.0	35960.9	.171	.186	1.4	.00368	90.20	324.81	233.33	421.45
90.400	36000.0	99000.0	35843.7	.188	.204	2.9	.00403	90.40	337.11	232.80	429.02
90.600	36000.0	99000.0	35648.4	.208	.225	4.7	.00444	90.60	352.53	232.29	442.08
90.800	36000.0	99000.0	35374.8	.232	.249	6.7	.00492	90.80	371.51	231.79	460.93
91.000	36000.0	99000.0	35023.2	.260	.278	9.2	.00548	91.01	392.20	231.31	486.47
91.200	36000.0	99000.0	34592.7	.304	.317	14.5	.00745	91.21	423.39	226.89	519.93
91.400	36000.0	99000.0	34084.5	.345	.361	17.7	.00791	91.41	458.34	224.91	563.91
91.600	36000.0	99000.0	33498.0	.394	.413	22.3	.00884	91.61	504.77	223.47	619.58
91.800	36000.0	99000.0	32833.3	.454	.475	28.3	.01004	91.81	552.29	222.33	689.30
92.000	36000.0	99000.0	32090.1	.527	.550	36.1	.01154	92.01	615.96	221.41	776.55
92.200	36000.0	99000.0	31268.5	.617	.642	46.0	.01340	92.21	691.74	220.65	886.00
92.400	36000.0	99000.0	30368.2	.729	.756	59.0	.01571	92.42	793.62	220.02	1024.26
92.600	36000.0	99000.0	29388.9	.876	.902	78.3	.01915	92.62	919.02	218.68	1200.88
92.800	36000.0	99000.0	28330.7	1.057	1.084	100.4	.02277	92.82	1074.04	217.81	1427.59
93.000	36000.0	99000.0	27193.2	1.291	1.315	130.7	.02752	93.03	1282.58	217.20	1721.33
93.200	36000.0	99000.0	25975.8	1.596	1.612	171.5	.03366	93.23	1546.18	216.73	2105.34
93.400	36000.0	99000.0	24678.0	1.998	1.997	227.0	.04164	93.44	1883.51	216.37	2614.00
93.600	36000.0	99000.0	23298.8	2.539	2.502	303.2	.05213	93.65	2316.37	216.09	3299.27
93.800	36000.0	99000.0	21837.1	3.280	3.171	409.0	.06607	93.87	2913.74	215.87	4238.54
94.000	36000.0	99000.0	20290.9	4.318	4.071	557.6	.08481	94.08	3701.28	215.70	5557.15
94.200	36000.0	99000.0	18658.0	5.794	5.294	762.0	.10942	94.31	4810.20	215.57	7450.76
94.400	36000.0	99000.0	16934.6	7.979	6.970	1055.4	.14324	94.54	6310.07	215.99	10260.91
94.600	36000.0	99000.0	15115.4	11.389	9.310	1494.6	.19157	94.79	8363.64	216.57	14653.33
94.800	36000.0	99000.0	13192.1	17.006	12.635	2135.1	.25875	95.06	11336.65	217.30	21903.65
95.000	36000.0	99000.0	11151.3	26.233	17.483	3115.3	.35656	95.36	15558.37	218.14	34712.29
95.200	36000.0	99000.0	8992.3	39.472	24.283	4207.3	.45961	95.66	21705.82	221.37	54850.00
95.400	36000.0	99000.0	6738.8	57.308	32.853	4990.3	.52874	95.93	29932.25	230.55	81620.46

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	37000.0	99000.0	37000.0	.023	.023	.0	.00045	81.00	196.04	242.91	371.94
82.000	37000.0	99000.0	37000.0	.025	.026	.0	.00051	82.00	196.91	242.81	371.94
83.000	37000.0	99000.0	37000.0	.028	.029	.0	.00057	83.00	198.10	242.67	371.94
84.000	37000.0	99000.0	37000.0	.032	.034	.0	.00066	84.00	199.76	242.48	371.94
85.000	37000.0	99000.0	37000.0	.038	.039	.0	.00077	85.00	202.15	242.20	371.94
86.000	37000.0	99000.0	37000.0	.045	.047	.0	.00092	86.00	205.76	241.77	371.94
87.000	37000.0	99000.0	37000.0	.056	.057	.0	.00114	87.00	211.44	241.10	371.94
88.000	37000.0	99000.0	37000.0	.071	.073	.0	.00146	88.00	220.89	240.00	371.94
89.200	37000.0	99000.0	37000.0	.104	.107	.0	.00214	89.20	242.61	237.66	371.94
89.400	37000.0	99000.0	37000.0	.112	.115	.0	.00230	89.40	248.17	237.12	371.94
89.600	37000.0	99000.0	37000.0	.121	.124	.0	.00248	89.60	254.56	236.55	371.94
89.800	37000.0	99000.0	37000.0	.131	.135	.0	.00268	89.80	261.89	235.93	371.94
90.000	37000.0	99000.0	37000.0	.133	.146	.0	.00292	90.00	270.22	235.30	359.95
90.200	37000.0	99000.0	36960.9	.146	.160	1.2	.00318	90.20	280.51	234.64	362.13
90.400	37000.0	99000.0	36843.7	.161	.176	2.5	.00349	90.40	291.02	233.98	368.62
90.600	37000.0	99000.0	36648.4	.179	.194	4.0	.00384	90.60	304.21	233.33	379.83
90.800	37000.0	99000.0	36374.9	.199	.215	5.8	.00425	90.80	320.46	232.70	396.01
91.000	37000.0	99000.0	36023.2	.223	.239	7.9	.00473	91.00	338.19	232.11	417.94
91.200	37000.0	99000.0	35593.4	.251	.268	10.4	.00529	91.21	363.46	231.55	446.13
91.400	37000.0	99000.0	35085.3	.284	.303	13.5	.00596	91.41	391.83	231.04	482.07
91.600	37000.0	99000.0	34498.5	.336	.350	20.3	.00795	91.61	431.83	226.53	528.39
91.800	37000.0	99000.0	33833.8	.387	.404	24.7	.00870	91.81	472.64	224.41	587.71
92.000	37000.0	99000.0	33090.8	.449	.469	31.1	.00992	92.01	527.10	222.93	661.97
92.200	37000.0	99000.0	32269.4	.525	.548	39.5	.01149	92.21	591.83	221.80	755.08
92.400	37000.0	99000.0	31369.5	.621	.646	50.5	.01346	92.41	678.85	220.90	872.65
92.600	37000.0	99000.0	30390.9	.740	.767	64.9	.01593	92.62	784.88	220.18	1021.57
92.800	37000.0	99000.0	29333.1	.898	.924	86.4	.01956	92.82	916.88	218.75	1213.13
93.000	37000.0	99000.0	28196.3	1.096	1.121	111.6	.02352	93.02	1094.70	217.84	1461.48
93.200	37000.0	99000.0	26980.0	1.353	1.375	146.3	.02873	93.23	1319.29	217.19	1785.58
93.400	37000.0	99000.0	25683.7	1.692	1.703	193.4	.03552	93.44	1606.66	216.71	2213.68
93.600	37000.0	99000.0	24306.4	2.145	2.132	258.1	.04444	93.64	1975.36	216.34	2788.26
93.800	37000.0	99000.0	22847.3	2.763	2.702	347.8	.05628	93.86	2483.76	216.05	3571.68
94.000	37000.0	99000.0	21304.7	3.623	3.465	473.6	.07218	94.07	3153.70	215.83	4663.59
94.200	37000.0	99000.0	19676.5	4.850	4.504	652.4	.09380	94.29	4096.38	215.67	6223.87
94.400	37000.0	99000.0	17959.8	6.630	5.928	899.2	.12234	94.52	5372.31	215.76	8507.57
94.600	37000.0	99000.0	16150.2	9.344	7.905	1267.3	.16304	94.76	7117.86	216.25	12010.90
94.800	37000.0	99000.0	14240.6	13.716	10.704	1803.4	.21963	95.02	9635.35	216.91	17647.98
95.000	37000.0	99000.0	12220.1	21.018	14.753	2616.1	.30143	95.30	13202.50	217.70	27450.31
95.200	37000.0	99000.0	10070.8	33.369	20.784	3889.7	.42312	95.62	18331.10	218.61	45264.71
95.400	37000.0	99000.0	7831.3	46.637	28.322	4387.9	.46777	95.87	25461.87	225.77	65548.48

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	38000.0	99000.0	38000.0	.019	.020	.0	.00039	81.00	169.90	245.43	320.14
82.000	38000.0	99000.0	38000.0	.022	.022	.0	.00044	82.00	170.67	245.34	320.14
83.000	38000.0	99000.0	38000.0	.024	.025	.0	.00049	83.00	171.71	245.21	320.14
84.000	38000.0	99000.0	38000.0	.028	.029	.0	.00057	84.00	173.16	245.03	320.14
85.000	38000.0	99000.0	38000.0	.032	.034	.0	.00066	85.00	175.25	244.77	320.14
86.000	38000.0	99000.0	38000.0	.039	.040	.0	.00079	86.00	178.40	244.36	320.14
87.000	38000.0	99000.0	38000.0	.048	.049	.0	.00098	87.00	183.35	243.71	320.14
88.000	38000.0	99000.0	38000.0	.061	.063	.0	.00126	88.00	191.56	242.61	320.14
89.200	38000.0	99000.0	38000.0	.090	.092	.0	.00185	89.20	210.28	240.08	320.14
89.400	38000.0	99000.0	38000.0	.096	.099	.0	.00200	89.40	215.05	239.47	320.14
89.600	38000.0	99000.0	38000.0	.104	.107	.0	.00216	89.60	220.50	238.78	320.14
89.800	38000.0	99000.0	38000.0	.113	.116	.0	.00233	89.80	226.76	238.03	320.14
90.000	38000.0	99000.0	38000.0	.114	.126	.0	.00253	90.00	233.85	237.23	309.27
90.200	38000.0	99000.0	37960.9	.126	.138	1.0	.00276	90.20	242.62	236.40	311.14
90.400	38000.0	99000.0	37843.7	.139	.151	2.2	.00302	90.40	251.56	235.55	316.71
90.600	38000.0	99000.0	37648.4	.154	.167	3.5	.00333	90.60	262.81	234.71	326.34
90.800	38000.0	99000.0	37374.9	.171	.185	5.0	.00368	90.80	276.69	233.90	340.23
91.000	38000.0	99000.0	37023.2	.191	.206	6.8	.00409	91.00	291.84	233.13	359.06
91.200	38000.0	99000.0	36593.4	.215	.231	9.0	.00457	91.20	313.50	232.42	383.26
91.400	38000.0	99000.0	36085.4	.244	.261	11.6	.00515	91.41	337.83	231.77	414.12
91.600	38000.0	99000.0	35499.2	.278	.296	14.9	.00583	91.61	370.22	231.18	452.96
91.800	38000.0	99000.0	34834.4	.319	.340	25.3	.00856	91.81	403.94	229.17	501.65
92.000	38000.0	99000.0	34091.4	.382	.399	27.3	.00866	92.01	451.09	225.21	564.39
92.200	38000.0	99000.0	33270.1	.447	.467	34.1	.00989	92.21	506.47	223.38	643.62
92.400	38000.0	99000.0	32370.5	.528	.551	43.3	.01154	92.41	580.81	222.06	743.64
92.600	38000.0	99000.0	31392.2	.630	.655	55.6	.01364	92.61	671.36	221.04	870.24
92.800	38000.0	99000.0	30335.2	.759	.786	71.7	.01630	92.82	782.97	220.25	1031.66
93.000	38000.0	99000.0	29198.6	.930	.956	95.8	.02018	93.02	934.45	218.72	1241.57
93.200	38000.0	99000.0	27983.4	1.148	1.172	124.9	.02455	93.22	1125.92	217.79	1515.44
93.400	38000.0	99000.0	26688.2	1.433	1.452	164.9	.03032	93.43	1370.78	217.14	1876.42
93.600	38000.0	99000.0	25312.6	1.815	1.818	219.9	.03790	93.64	1684.90	216.65	2359.37
93.800	38000.0	99000.0	23855.7	2.332	2.302	296.0	.04797	93.85	2117.74	216.28	3014.96
94.000	38000.0	99000.0	22316.1	3.047	2.951	402.7	.06147	94.06	2687.89	216.00	3923.15
94.200	38000.0	99000.0	20692.1	4.059	3.832	553.8	.07980	94.28	3488.88	215.79	5209.77
94.400	38000.0	99000.0	18980.9	5.525	5.043	767.7	.10465	94.50	4574.40	215.63	7082.31
94.600	38000.0	99000.0	17179.3	7.722	6.719	1076.5	.13891	94.74	6059.05	215.98	9903.25
94.800	38000.0	99000.0	15281.1	11.163	9.081	1526.8	.18672	94.99	8101.55	216.56	14347.64
95.000	38000.0	99000.0	13277.4	16.976	12.478	2204.4	.25542	95.26	11085.21	217.29	21849.45
95.200	38000.0	99000.0	11153.7	26.442	17.489	3253.8	.35667	95.56	15543.19	218.15	35423.75
95.400	38000.0	99000.0	8913.9	39.233	24.427	4081.1	.43315	95.83	21840.59	221.70	54501.58
95.600	38000.0	99000.0	6563.1	64.281	33.871	5767.5	.57828	96.18	30531.20	231.32	92123.65

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
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APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	39000.0	99000.0	39000.0	.017	.017	.0	.00034	81.00	147.58	248.38	275.56
82.000	39000.0	99000.0	39000.0	.019	.019	.0	.00038	82.00	148.25	248.31	275.56
83.000	39000.0	99000.0	39000.0	.021	.022	.0	.00043	83.00	149.17	248.20	275.56
84.000	39000.0	99000.0	39000.0	.024	.025	.0	.00049	84.00	150.44	248.04	275.56
85.000	39000.0	99000.0	39000.0	.028	.029	.0	.00057	85.00	152.28	247.81	275.56
86.000	39000.0	99000.0	39000.0	.033	.035	.0	.00068	86.00	155.05	247.46	275.56
87.000	39000.0	99000.0	39000.0	.041	.042	.0	.00085	87.00	159.40	246.88	275.56
88.000	39000.0	99000.0	39000.0	.053	.054	.0	.00110	88.00	166.59	245.89	275.56
89.200	39000.0	99000.0	39000.0	.077	.079	.0	.00163	89.20	182.85	243.44	275.56
89.400	39000.0	99000.0	39000.0	.083	.085	.0	.00176	89.40	186.94	242.77	275.56
89.600	39000.0	99000.0	39000.0	.089	.091	.0	.00190	89.60	191.61	241.99	275.56
89.800	39000.0	99000.0	39000.0	.097	.099	.0	.00206	89.80	196.94	241.09	275.56
90.000	39000.0	99000.0	39000.0	.098	.108	.0	.00224	90.00	202.95	240.07	265.72
90.200	39000.0	99000.0	38960.9	.108	.118	.9	.00243	90.20	210.38	238.96	267.32
90.400	39000.0	99000.0	38843.7	.119	.130	1.9	.00265	90.40	217.94	237.80	272.10
90.600	39000.0	99000.0	38648.4	.132	.143	3.1	.00290	90.60	227.46	236.65	280.37
90.800	39000.0	99000.0	38374.9	.147	.159	4.4	.00320	90.80	239.26	235.54	292.30
91.000	39000.0	99000.0	38023.2	.164	.177	5.9	.00354	91.00	252.14	234.51	308.47
91.200	39000.0	99000.0	37593.4	.185	.199	7.8	.00396	91.20	270.66	233.56	329.25
91.400	39000.0	99000.0	37085.5	.209	.225	10.0	.00445	91.40	291.48	232.72	355.74
91.600	39000.0	99000.0	36499.3	.238	.255	12.8	.00504	91.61	319.25	231.96	389.10
91.800	39000.0	99000.0	35834.9	.273	.292	16.3	.00575	91.81	347.74	231.30	430.46
92.000	39000.0	99000.0	35092.3	.316	.336	20.7	.00661	92.01	385.72	230.72	482.09
92.200	39000.0	99000.0	34270.6	.381	.397	30.2	.00870	92.21	433.39	225.82	548.73
92.400	39000.0	99000.0	33371.1	.450	.470	37.4	.00995	92.41	497.04	223.67	633.56
92.600	39000.0	99000.0	32393.1	.536	.559	47.7	.01170	92.61	574.39	222.19	741.20
92.800	39000.0	99000.0	31336.5	.646	.681	61.4	.01396	92.81	669.69	221.09	878.70
93.000	39000.0	99000.0	30201.0	.786	.813	79.7	.01684	93.02	797.63	220.25	1054.97
93.200	39000.0	99000.0	28986.1	.974	.999	107.0	.02103	93.22	961.02	218.60	1286.51
93.400	39000.0	99000.0	27691.8	1.215	1.238	140.8	.02590	93.43	1169.75	217.69	1591.79
93.600	39000.0	99000.0	26317.6	1.537	1.550	187.4	.03235	93.63	1437.43	217.04	1998.58
93.800	39000.0	99000.0	24862.5	1.970	1.963	252.1	.04091	93.84	1806.05	216.56	2548.72
94.000	39000.0	99000.0	23325.4	2.567	2.515	342.6	.05238	94.05	2291.46	216.20	3305.98
94.200	39000.0	99000.0	21704.9	3.406	3.263	470.6	.06794	94.27	2972.48	215.93	4372.11
94.400	39000.0	99000.0	19998.6	4.618	4.289	654.3	.08933	94.49	3894.54	215.73	5913.91
94.600	39000.0	99000.0	18203.5	6.405	5.714	915.8	.11848	94.72	5158.60	215.77	8205.99
94.800	39000.0	99000.0	16315.0	9.164	7.712	1295.1	.15893	94.96	6896.54	216.24	11752.57
95.000	39000.0	99000.0	14325.2	13.672	10.572	1862.7	.21683	95.22	9428.31	216.90	17578.40
95.200	39000.0	99000.0	12222.5	21.397	14.759	2733.2	.30153	95.50	13189.19	217.71	27931.05
95.400	39000.0	99000.0	9988.0	33.986	21.005	3935.4	.41331	95.81	18676.92	218.65	46087.65
95.600	39000.0	99000.0	7665.0	50.994	29.102	4956.2	.50144	96.10	26205.18	226.85	72131.73

UNREFRACTED RAY STRIKES OISC



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	MDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	40000.0	99000.0	40000.0	.014	.015	.0	.00027	81.00	128.72	251.80	237.19
82.000	40000.0	99000.0	40000.0	.016	.017	.0	.00030	82.00	129.32	251.75	237.19
83.000	40000.0	99000.0	40000.0	.018	.019	.0	.00034	83.00	130.13	251.67	237.19
84.000	40000.0	99000.0	40000.0	.021	.021	.0	.00039	84.00	131.26	251.56	237.19
85.000	40000.0	99000.0	40000.0	.024	.025	.0	.00046	85.00	132.90	251.39	237.19
86.000	40000.0	99000.0	40000.0	.029	.030	.0	.00055	86.00	135.35	251.13	237.19
87.000	40000.0	99000.0	40000.0	.035	.036	.0	.00067	87.00	139.22	250.72	237.19
88.000	40000.0	99000.0	40000.0	.046	.047	.0	.00086	88.00	145.63	250.04	237.19
89.200	40000.0	99000.0	40000.0	.066	.067	.0	.00124	89.20	160.10	248.65	237.19
89.400	40000.0	99000.0	40000.0	.071	.072	.0	.00133	89.40	163.69	248.35	237.19
89.600	40000.0	99000.0	40000.0	.077	.078	.0	.00144	89.60	167.71	248.03	237.19
89.800	40000.0	99000.0	40000.0	.083	.084	.0	.00155	89.80	172.18	247.70	237.19
90.000	40000.0	99000.0	40000.0	.076	.091	.0	.00168	90.00	177.04	247.36	229.12
90.200	40000.0	99000.0	39960.9	.085	.099	.8	.00237	90.20	182.96	245.62	230.41
90.400	40000.0	99000.0	39843.5	.094	.109	2.1	.00316	90.40	189.23	242.99	234.28
90.600	40000.0	99000.0	39648.0	.113	.122	3.0	.00311	90.60	197.40	239.95	240.89
90.800	40000.0	99000.0	39374.5	.126	.136	4.0	.00310	90.80	207.40	238.10	251.13
91.000	40000.0	99000.0	39022.9	.141	.152	5.2	.00330	91.00	218.26	236.52	264.90
91.200	40000.0	99000.0	38593.1	.159	.171	6.8	.00360	91.20	234.02	235.17	282.86
91.400	40000.0	99000.0	38085.1	.180	.193	8.7	.00399	91.40	251.78	234.00	305.62
91.600	40000.0	99000.0	37498.9	.205	.219	11.1	.00447	91.60	275.55	232.99	334.26
91.800	40000.0	99000.0	36834.6	.235	.251	14.1	.00507	91.81	299.95	232.12	369.77
92.000	40000.0	99000.0	36092.0	.271	.289	17.9	.00579	92.01	332.54	231.38	414.10
92.200	40000.0	99000.0	35271.1	.316	.335	22.7	.00669	92.21	371.20	230.75	469.47
92.400	40000.0	99000.0	34371.2	.383	.399	33.4	.00888	92.41	425.32	226.20	540.17
92.600	40000.0	99000.0	33393.5	.457	.477	41.2	.01016	92.61	491.58	223.78	631.71
92.800	40000.0	99000.0	32337.1	.550	.573	52.7	.01204	92.81	572.99	222.20	748.65
93.000	40000.0	99000.0	31202.0	.669	.695	68.3	.01448	93.01	682.24	221.05	898.43
93.200	40000.0	99000.0	29988.0	.823	.850	90.7	.01787	93.22	820.01	220.18	1093.17
93.400	40000.0	99000.0	28694.3	1.031	1.056	120.4	.02221	93.42	998.44	218.41	1351.33
93.600	40000.0	99000.0	27321.1	1.302	1.322	159.9	.02767	93.63	1226.62	217.54	1694.00
93.800	40000.0	99000.0	25867.6	1.667	1.674	214.9	.03495	93.83	1540.65	216.91	2156.64
94.000	40000.0	99000.0	24332.7	2.167	2.144	291.7	.04470	94.04	1954.05	216.45	2791.52
94.200	40000.0	99000.0	22715.1	2.865	2.780	400.3	.05792	94.26	2533.41	216.11	3678.96
94.400	40000.0	99000.0	21013.0	3.865	3.651	555.6	.07605	94.48	3278.25	215.86	4949.95
94.600	40000.0	99000.0	19223.3	5.337	4.862	781.1	.10128	94.70	4392.62	215.67	6829.92
94.800	40000.0	99000.0	17342.8	7.561	6.556	1100.5	.13248	94.94	5872.21	215.98	9685.97
95.000	40000.0	99000.0	15364.7	11.114	8.971	1577.6	.18440	95.18	8022.43	216.55	14274.17
95.200	40000.0	99000.0	13279.4	17.228	12.483	2303.8	.25555	95.46	11074.81	217.30	22187.63
95.400	40000.0	99000.0	11070.8	27.505	17.732	3442.0	.36176	95.76	15674.42	218.18	36834.36
95.600	40000.0	99000.0	8754.3	39.665	24.844	4002.1	.41254	96.01	22146.34	222.84	55091.03

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

MIOLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	41000.0	99000.0	41000.0	.012	.013	.0	.00024	81.00	111.81	253.14	206.62
82.000	41000.0	99000.0	41000.0	.014	.014	.0	.00026	82.00	112.33	253.09	206.62
83.000	41000.0	99000.0	41000.0	.016	.016	.0	.00030	83.00	113.03	253.02	206.62
84.000	41000.0	99000.0	41000.0	.018	.019	.0	.00034	84.00	114.02	252.91	206.62
85.000	41000.0	99000.0	41000.0	.021	.022	.0	.00040	85.00	115.45	252.75	206.62
86.000	41000.0	99000.0	41000.0	.025	.026	.0	.00048	86.00	117.60	252.50	206.62
87.000	41000.0	99000.0	41000.0	.031	.032	.0	.00059	87.00	120.97	252.09	206.62
88.000	41000.0	99000.0	41000.0	.039	.040	.0	.00075	88.00	126.56	251.37	206.62
89.200	41000.0	99000.0	41000.0	.056	.058	.0	.00108	89.20	139.16	249.82	206.62
89.400	41000.0	99000.0	41000.0	.061	.063	.0	.00116	89.40	142.29	249.47	206.62
89.600	41000.0	99000.0	41000.0	.065	.067	.0	.00125	89.60	145.79	249.09	206.62
89.800	41000.0	99000.0	41000.0	.071	.073	.0	.00135	89.80	149.67	248.69	206.62
90.000	41000.0	99000.0	41000.0	.071	.079	.0	.00147	90.00	153.90	248.27	198.74
90.200	41000.0	99000.0	40960.9	.078	.086	.6	.00160	90.20	160.78	247.84	199.85
90.400	41000.0	99000.0	40843.7	.085	.094	1.3	.00175	90.40	167.43	247.41	203.18
90.600	41000.0	99000.0	40648.4	.094	.104	2.0	.00192	90.60	173.75	246.99	209.23
91.000	41000.0	99000.0	40023.3	.117	.127	3.9	.00234	91.00	185.13	246.18	228.49
91.200	41000.0	99000.0	39593.1	.138	.145	6.7	.00343	91.20	204.13	240.01	243.01
91.400	41000.0	99000.0	39085.1	.156	.165	7.8	.00354	91.40	218.90	237.37	262.54
91.600	41000.0	99000.0	38499.0	.177	.188	9.8	.00391	91.60	238.98	235.49	287.14
91.800	41000.0	99000.0	37834.6	.203	.215	12.3	.00439	91.80	259.67	234.03	317.63
92.000	41000.0	99000.0	37092.0	.234	.248	15.5	.00501	92.00	287.49	232.85	355.68
92.200	41000.0	99000.0	36271.2	.273	.288	19.6	.00577	92.20	320.57	231.90	403.22
92.400	41000.0	99000.0	35372.1	.320	.337	24.9	.00672	92.40	364.86	231.11	462.38
92.600	41000.0	99000.0	34394.0	.390	.405	36.8	.00899	92.60	421.01	226.58	538.53
92.800	41000.0	99000.0	33337.8	.469	.488	45.5	.01037	92.80	490.70	223.95	637.95
93.000	41000.0	99000.0	32203.1	.570	.593	58.6	.01242	93.00	584.00	222.27	765.29
93.200	41000.0	99000.0	30989.5	.701	.726	76.4	.01510	93.20	701.58	221.06	930.48
93.400	41000.0	99000.0	29696.5	.877	.899	105.5	.01938	93.40	852.41	219.60	1148.18
93.600	41000.0	99000.0	28324.3	1.105	1.127	136.7	.02365	93.60	1047.13	218.25	1437.30
93.800	41000.0	99000.0	26872.0	1.413	1.427	183.3	.02983	93.80	1314.71	217.41	1827.18
94.000	41000.0	99000.0	25338.8	1.833	1.828	248.5	.03813	94.00	1666.85	216.80	2360.28
94.200	41000.0	99000.0	23723.7	2.416	2.369	340.7	.04936	94.20	2159.90	216.36	3101.58
94.400	41000.0	99000.0	22025.1	3.245	3.109	472.3	.06476	94.40	2793.98	216.04	4155.49
94.600	41000.0	99000.0	20240.4	4.457	4.135	662.8	.08614	94.60	3740.22	215.80	5697.62
94.800	41000.0	99000.0	18366.4	6.271	5.576	936.6	.11558	94.80	5000.67	215.80	8023.86
95.000	41000.0	99000.0	16398.1	9.115	7.619	1338.6	.15697	95.00	6828.05	216.24	11679.42
95.200	41000.0	99000.0	14327.2	13.858	10.577	1947.0	.21694	95.20	9419.47	216.92	17806.05
95.400	41000.0	99000.0	12140.6	22.199	14.961	2891.3	.30578	95.40	13305.99	217.74	28967.32
95.600	41000.0	99000.0	9828.9	33.635	21.340	3700.7	.37989	95.60	18946.83	219.40	45601.93
95.800	41000.0	99000.0	7402.4	57.051	30.312	5615.1	.54153	95.80	27224.97	227.74	81217.10

UNREFRACTED RAY STRIKES DISC



LATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	42000.0	99000.0	42000.0	.011	.011	.0	.00021	81.00	97.09	254.69	179.55
82.000	42000.0	99000.0	42000.0	.012	.013	.0	.00023	82.00	97.55	254.65	179.55
83.000	42000.0	99000.0	42000.0	.014	.014	.0	.00026	83.00	98.16	254.58	179.55
84.000	42000.0	99000.0	42000.0	.016	.016	.0	.00030	84.00	99.03	254.49	179.55
85.000	42000.0	99000.0	42000.0	.018	.019	.0	.00035	85.00	100.27	254.35	179.55
86.000	42000.0	99000.0	42000.0	.022	.022	.0	.00041	86.00	102.14	254.12	179.55
87.000	42000.0	99000.0	42000.0	.027	.028	.0	.00051	87.00	105.08	253.72	179.55
88.000	42000.0	99000.0	42000.0	.034	.035	.0	.00065	88.00	109.96	253.01	179.55
89.200	42000.0	99000.0	42000.0	.049	.051	.0	.00095	89.20	120.95	251.32	179.55
89.400	42000.0	99000.0	42000.0	.053	.054	.0	.00102	89.40	123.67	250.91	179.55
89.600	42000.0	99000.0	42000.0	.057	.059	.0	.00110	89.60	126.72	250.46	179.55
89.800	42000.0	99000.0	42000.0	.061	.063	.0	.00119	89.80	130.10	249.97	179.55
90.000	42000.0	99000.0	42000.0	.061	.069	.0	.00128	90.00	133.78	249.46	172.38
90.200	42000.0	99000.0	41960.9	.067	.075	.5	.00140	90.20	139.77	248.93	173.34
90.400	42000.0	99000.0	41843.7	.074	.082	1.1	.00152	90.40	145.55	248.39	176.23
90.600	42000.0	99000.0	41648.4	.082	.090	1.8	.00167	90.60	151.04	247.85	181.48
91.000	42000.0	99000.0	41374.9	.091	.099	2.5	.00184	90.80	156.18	247.33	188.61
91.000	42000.0	99000.0	41023.2	.101	.110	3.4	.00204	91.00	160.92	246.84	198.19
91.200	42000.0	99000.0	40593.4	.113	.123	4.4	.00227	91.20	173.89	246.38	210.93
91.400	42000.0	99000.0	40085.4	.127	.138	5.7	.00255	91.40	178.57	245.95	226.57
91.600	42000.0	99000.0	39498.9	.152	.160	9.2	.00361	91.60	208.27	239.66	246.68
91.800	42000.0	99000.0	38834.6	.174	.184	10.9	.00386	91.80	225.48	236.82	272.84
92.000	42000.0	99000.0	38092.0	.201	.213	13.5	.00435	92.00	249.03	234.88	305.52
92.200	42000.0	99000.0	37271.2	.234	.248	17.0	.00499	92.20	277.22	233.42	346.33
92.400	42000.0	99000.0	36372.1	.274	.290	21.5	.00580	92.41	315.12	232.27	397.11
92.600	42000.0	99000.0	35394.7	.324	.342	27.4	.00681	92.61	361.17	231.35	460.99
92.800	42000.0	99000.0	34338.3	.400	.415	40.4	.00914	92.81	420.25	226.63	543.80
93.000	42000.0	99000.0	33203.7	.485	.505	50.5	.01069	93.01	500.08	223.92	652.04
93.200	42000.0	99000.0	31990.5	.596	.619	65.5	.01294	93.21	600.47	222.20	792.45
93.400	42000.0	99000.0	30698.4	.741	.766	86.0	.01591	93.42	728.62	220.97	975.89
93.600	42000.0	99000.0	29326.6	.938	.960	117.5	.02032	93.62	894.02	219.24	1220.39
93.800	42000.0	99000.0	27875.4	1.198	1.217	156.5	.02549	93.83	1122.15	218.04	1549.40
94.000	42000.0	99000.0	26343.7	1.551	1.558	211.9	.03254	94.03	1422.18	217.24	1998.04
94.200	42000.0	99000.0	24730.7	2.039	2.019	290.2	.04209	94.24	1841.94	216.67	2618.36
94.400	42000.0	99000.0	23034.9	2.730	2.649	401.8	.05318	94.46	2381.90	216.25	3496.72
94.600	42000.0	99000.0	21254.3	3.730	3.520	563.1	.07331	94.67	3148.07	215.95	4768.29
94.800	42000.0	99000.0	19385.9	5.222	4.744	799.4	.09881	94.90	4258.76	215.73	6674.15
95.000	42000.0	99000.0	17425.9	7.513	6.477	1137.6	.13377	95.13	5812.83	215.99	9616.01
95.200	42000.0	99000.0	15367.0	11.245	8.974	1649.2	.18445	95.38	8014.63	216.57	14432.33
95.400	42000.0	99000.0	13198.7	17.817	12.651	2436.9	.25907	95.66	11302.67	217.33	22937.67
95.600	42000.0	99000.0	10903.6	29.034	18.207	3649.0	.36857	95.97	16144.98	218.26	38872.79
95.800	42000.0	99000.0	8495.8	45.796	26.009	4909.6	.47605	96.28	23313.46	223.73	64336.57

UNREFRACTED RAY STRIKES DISC



## REFRACTION AIRMASS TABLES

## MIDLATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	43000.0	99000.0	43000.0	.009	.010	.0	.00018	81.00	84.29	256.48	156.03
82.000	43000.0	99000.0	43000.0	.010	.011	.0	.00020	82.00	84.68	256.45	156.03
83.000	43000.0	99000.0	43000.0	.012	.012	.0	.00023	83.00	85.22	256.40	156.03
84.000	43000.0	99000.0	43000.0	.014	.014	.0	.00026	84.00	85.97	256.33	156.03
85.000	43000.0	99000.0	43000.0	.016	.016	.0	.00030	85.00	87.06	256.22	156.03
86.000	43000.0	99000.0	43000.0	.019	.020	.0	.00036	86.00	88.68	256.03	156.03
87.000	43000.0	99000.0	43000.0	.023	.024	.0	.00044	87.00	91.25	255.68	156.03
88.000	43000.0	99000.0	43000.0	.029	.031	.0	.00057	88.00	95.49	255.03	156.03
89.200	43000.0	99000.0	43000.0	.043	.044	.0	.00083	89.20	105.06	253.29	156.03
89.400	43000.0	99000.0	43000.0	.046	.047	.0	.00090	89.40	107.44	252.83	156.03
89.600	43000.0	99000.0	43000.0	.049	.051	.0	.00097	89.60	110.10	252.30	156.03
89.800	43000.0	99000.0	43000.0	.053	.055	.0	.00104	89.80	113.05	251.71	156.03
90.000	43000.0	99000.0	43000.0	.058	.060	.0	.00113	90.00	116.26	251.07	149.51
90.200	43000.0	99000.0	42960.9	.064	.065	.5	.00123	90.20	121.48	250.39	150.34
90.400	43000.0	99000.0	42843.7	.071	.071	1.0	.00134	90.40	126.51	249.70	152.85
90.600	43000.0	99000.0	42648.3	.078	.078	1.5	.00147	90.60	131.29	249.00	157.41
90.800	43000.0	99000.0	42374.8	.086	.086	2.2	.00161	90.80	135.76	248.33	163.59
91.000	43000.0	99000.0	42023.1	.088	.096	3.0	.00178	91.00	139.88	247.69	171.89
91.200	43000.0	99000.0	41593.3	.098	.107	3.9	.00198	91.20	151.15	247.10	182.95
91.400	43000.0	99000.0	41085.3	.111	.120	5.0	.00222	91.40	155.21	246.56	196.51
91.600	43000.0	99000.0	40499.1	.125	.136	6.3	.00250	91.60	175.17	246.07	213.79
91.800	43000.0	99000.0	39834.6	.143	.155	11.9	.00403	91.80	196.94	243.46	234.90
92.000	43000.0	99000.0	39091.9	.172	.182	12.1	.00386	92.00	216.47	237.95	262.44
92.200	43000.0	99000.0	38271.1	.201	.212	14.8	.00435	92.20	240.24	235.53	297.48
92.400	43000.0	99000.0	37372.0	.235	.249	18.7	.00502	92.40	272.54	233.80	341.07
92.600	43000.0	99000.0	36394.7	.278	.294	23.7	.00588	92.60	311.94	232.50	395.90
92.800	43000.0	99000.0	35339.0	.332	.351	30.3	.00696	92.80	360.37	231.48	465.06
93.000	43000.0	99000.0	34204.1	.413	.430	44.4	.00936	93.00	428.27	226.39	555.74
93.200	43000.0	99000.0	32991.2	.508	.528	56.3	.01113	93.20	514.11	223.72	675.09
93.400	43000.0	99000.0	31699.4	.630	.654	73.7	.01363	93.40	623.51	222.01	830.94
93.600	43000.0	99000.0	30328.6	.792	.817	97.7	.01695	93.60	763.57	220.80	1036.94
93.800	43000.0	99000.0	28878.0	1.016	1.037	134.0	.02182	93.80	957.97	218.88	1314.86
94.000	43000.0	99000.0	27347.5	1.313	1.329	180.8	.02779	94.00	1213.69	217.79	1692.52
94.200	43000.0	99000.0	25736.2	1.724	1.722	247.3	.03591	94.20	1571.18	217.05	2214.15
94.400	43000.0	99000.0	24042.9	2.301	2.257	342.1	.04704	94.40	2031.11	216.52	2947.31
94.600	43000.0	99000.0	22265.7	3.131	2.998	478.8	.06244	94.60	2683.18	216.14	4002.76
94.800	43000.0	99000.0	20402.3	4.359	4.036	678.6	.08405	94.80	3626.99	215.86	5565.59
95.000	43000.0	99000.0	18448.9	6.225	5.509	988.4	.11413	95.00	4949.35	215.82	7958.02
95.200	43000.0	99000.0	16400.2	9.205	7.623	1399.5	.15170	95.20	6821.38	216.26	11788.04
95.400	43000.0	99000.0	14247.1	14.289	10.718	2059.8	.21992	95.40	9606.10	216.95	18353.46
95.600	43000.0	99000.0	11975.0	23.132	15.362	3080.5	.31284	95.60	13698.35	217.80	30576.07
95.800	43000.0	99000.0	9578.1	37.412	22.245	4307.8	.41937	95.80	19706.89	220.42	51335.40
96.000	43000.0	99000.0	7049.8	64.563	31.950	6286.6	.58076	96.00	28527.65	228.70	92500.58



# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
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UNREFRACTED RAY STRIKES DISC

# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
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APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	44000.0	99000.0	44000.0	.008	.009	.0	.00016	81.00	73.14	258.56	135.59
82.000	44000.0	99000.0	44000.0	.009	.010	.0	.00017	82.00	73.48	258.54	135.59
83.000	44000.0	99000.0	44000.0	.010	.011	.0	.00020	83.00	73.95	258.52	135.59
84.000	44000.0	99000.0	44000.0	.012	.012	.0	.00023	84.00	74.60	258.48	135.59
85.000	44000.0	99000.0	44000.0	.014	.014	.0	.00026	85.00	75.54	258.41	135.59
86.000	44000.0	99000.0	44000.0	.016	.017	.0	.00031	86.00	76.95	258.29	135.59
87.000	44000.0	99000.0	44000.0	.020	.021	.0	.00039	87.00	79.17	258.06	135.59
88.000	44000.0	99000.0	44000.0	.026	.026	.0	.00050	88.00	82.85	257.57	135.59
89.200	44000.0	99000.0	44000.0	.037	.038	.0	.00075	89.20	91.12	256.06	135.59
89.400	44000.0	99000.0	44000.0	.040	.041	.0	.00081	89.40	93.17	255.59	135.59
89.600	44000.0	99000.0	44000.0	.043	.044	.0	.00089	89.60	95.48	255.01	135.59
89.800	44000.0	99000.0	44000.0	.046	.047	.0	.00097	89.80	98.05	254.31	135.59
90.000	44000.0	99000.0	44000.0	.046	.051	.0	.00108	90.00	100.87	253.49	129.67
90.200	44000.0	99000.0	43960.9	.050	.056	.4	.00113	90.20	105.46	252.58	130.39
90.400	44000.0	99000.0	43843.7	.055	.062	.9	.00121	90.40	109.89	251.61	132.56
90.600	44000.0	99000.0	43648.3	.061	.068	1.4	.00130	90.60	114.08	250.64	136.52
90.800	44000.0	99000.0	43374.7	.068	.075	1.9	.00142	90.80	117.98	249.71	141.88
91.000	44000.0	99000.0	43023.0	.076	.083	2.6	.00157	91.00	121.57	248.84	149.08
91.200	44000.0	99000.0	42593.2	.085	.093	3.4	.00174	91.20	131.38	248.05	158.67
91.400	44000.0	99000.0	42085.1	.096	.104	4.3	.00194	91.40	134.91	247.34	170.43
91.600	44000.0	99000.0	41498.9	.109	.118	5.5	.00218	91.60	152.26	246.71	185.43
91.800	44000.0	99000.0	40834.6	.124	.134	7.0	.00247	91.80	170.94	246.16	203.61
92.000	44000.0	99000.0	40092.0	.142	.153	8.8	.00282	92.00	177.60	245.68	226.45
92.200	44000.0	99000.0	39270.8	.172	.181	13.4	.00390	92.20	208.99	238.83	255.42
92.400	44000.0	99000.0	38371.8	.202	.214	16.3	.00437	92.40	236.24	235.95	292.95
92.600	44000.0	99000.0	37394.5	.239	.253	20.5	.00509	92.61	269.79	234.02	340.02
92.800	44000.0	99000.0	36338.8	.285	.302	26.2	.00601	92.81	311.22	232.59	399.38
93.000	44000.0	99000.0	35204.8	.344	.363	33.7	.00719	93.01	366.65	231.51	474.95
93.200	44000.0	99000.0	33991.5	.432	.450	49.1	.00968	93.21	440.27	225.94	575.29
93.400	44000.0	99000.0	32700.1	.537	.558	63.3	.01171	93.41	533.74	223.40	707.75
93.600	44000.0	99000.0	31329.7	.674	.698	83.6	.01452	93.61	653.30	221.74	882.70
93.800	44000.0	99000.0	29880.0	.863	.883	117.4	.01903	93.82	817.59	220.40	1116.92
94.000	44000.0	99000.0	28350.4	1.114	1.133	154.5	.02376	94.02	1035.98	218.51	1435.41
94.200	44000.0	99000.0	26740.5	1.459	1.468	210.9	.03066	94.23	1340.54	217.53	1874.54
94.400	44000.0	99000.0	25049.2	1.943	1.925	291.5	.04012	94.44	1732.39	216.85	2489.01
94.600	44000.0	99000.0	23275.0	2.634	2.555	407.5	.05321	94.65	2287.56	216.36	3368.05
94.800	44000.0	99000.0	21415.7	3.648	3.436	576.7	.07155	94.87	3090.05	216.02	4657.74
95.000	44000.0	99000.0	19468.0	5.182	4.688	827.1	.09762	95.10	4214.48	215.77	6616.86
95.200	44000.0	99000.0	17427.8	7.577	6.480	1189.6	.13382	95.33	5807.13	216.02	9692.21
95.400	44000.0	99000.0	15287.3	11.562	9.093	1744.7	.18697	95.59	8077.99	216.60	14833.88
95.600	44000.0	99000.0	13034.5	18.785	12.991	2609.5	.26618	95.87	11501.71	217.38	24177.19
95.800	44000.0	99000.0	10650.7	31.098	18.960	3962.5	.38431	96.18	16788.94	218.43	42153.06
96.000	44000.0	99000.0	8147.5	51.558	27.431	5521.6	.51262	96.51	24463.15	224.56	72906.69



# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
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UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

MIOLATITUDE WINTER  
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APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	45000.0	99000.0	45000.0	.007	.007	.0	.00013	81.00	63.76	260.88	117.82
82.000	45000.0	99000.0	45000.0	.008	.008	.0	.00014	82.00	64.06	260.89	117.82
83.000	45000.0	99000.0	45000.0	.009	.009	.0	.00016	83.00	64.46	260.90	117.82
84.000	45000.0	99000.0	45000.0	.010	.011	.0	.00018	84.00	65.03	260.90	117.82
85.000	45000.0	99000.0	45000.0	.012	.012	.0	.00021	85.00	65.85	260.90	117.82
86.000	45000.0	99000.0	45000.0	.014	.015	.0	.00025	86.00	67.08	260.89	117.82
87.000	45000.0	99000.0	45000.0	.017	.018	.0	.00031	87.00	69.01	260.84	117.82
88.000	45000.0	99000.0	45000.0	.022	.023	.0	.00040	88.00	72.20	260.70	117.82
89.200	45000.0	99000.0	45000.0	.032	.033	.0	.00057	89.20	79.33	260.33	117.82
89.400	45000.0	99000.0	45000.0	.035	.035	.0	.00061	89.40	81.09	260.24	117.82
89.600	45000.0	99000.0	45000.0	.037	.038	.0	.00065	89.60	83.06	260.14	117.82
89.800	45000.0	99000.0	45000.0	.040	.041	.0	.00071	89.80	85.24	260.03	117.82
90.000	45000.0	99000.0	45000.0	.036	.044	.0	.00076	90.00	87.61	259.92	113.23
90.200	45000.0	99000.0	44960.9	.040	.048	.3	.00089	90.20	91.43	258.62	113.82
90.400	45000.0	99000.0	44843.6	.045	.053	.7	.00103	90.40	95.18	257.23	115.61
90.600	45000.0	99000.0	44648.2	.053	.058	1.2	.00119	90.60	98.83	255.54	118.40
90.800	45000.0	99000.0	44374.6	.059	.064	1.8	.00138	90.80	102.33	253.41	123.05
91.000	45000.0	99000.0	44022.8	.066	.072	2.6	.00162	91.00	105.62	250.71	129.30
91.200	45000.0	99000.0	43592.9	.074	.080	3.0	.00162	91.20	114.08	249.43	137.62
91.400	45000.0	99000.0	43084.8	.083	.090	3.8	.00177	91.40	117.19	248.43	147.82
91.600	45000.0	99000.0	42498.5	.094	.102	4.8	.00196	91.60	132.34	247.58	160.83
91.800	45000.0	99000.0	41834.1	.107	.116	6.1	.00221	91.80	148.61	246.85	176.59
92.000	45000.0	99000.0	41091.5	.123	.133	7.6	.00250	92.00	154.39	246.23	196.41
92.200	45000.0	99000.0	40270.7	.142	.153	9.6	.00287	92.20	174.89	245.70	220.87
92.400	45000.0	99000.0	39371.3	.173	.182	14.9	.00399	92.40	205.64	239.38	251.66
92.600	45000.0	99000.0	38394.0	.205	.217	17.9	.00447	92.60	233.90	236.14	292.05
92.800	45000.0	99000.0	37338.4	.245	.259	22.7	.00523	92.81	269.19	234.06	343.00
93.000	45000.0	99000.0	36204.4	.295	.312	29.1	.00623	93.01	316.65	232.56	407.86
93.200	45000.0	99000.0	34992.0	.359	.379	39.9	.00789	93.21	376.28	231.43	491.01
93.400	45000.0	99000.0	33700.2	.457	.475	54.8	.01015	93.41	457.10	225.34	603.03
93.600	45000.0	99000.0	32330.2	.574	.596	71.7	.01248	93.61	559.21	222.98	751.70
93.800	45000.0	99000.0	30881.2	.729	.753	95.7	.01566	93.82	699.29	221.41	949.69
94.000	45000.0	99000.0	29352.3	.945	.966	132.9	.02044	94.02	884.47	219.51	1218.39
94.200	45000.0	99000.0	27743.6	1.237	1.252	180.0	.02621	94.23	1144.10	218.14	1588.64
94.400	45000.0	99000.0	26053.9	1.643	1.641	248.5	.03425	94.43	1478.01	217.26	2104.95
94.600	45000.0	99000.0	24282.1	2.220	2.178	347.0	.04538	94.65	1950.84	216.64	2838.80
94.800	45000.0	99000.0	22426.3	3.061	2.927	490.5	.06096	94.86	2633.56	216.21	3908.15
95.000	45000.0	99000.0	20483.8	4.323	3.988	702.3	.08306	95.08	3589.04	215.90	5514.72
95.200	45000.0	99000.0	18450.5	6.272	5.512	1012.8	.11419	95.31	4944.66	215.84	8013.82
95.400	45000.0	99000.0	16320.6	9.436	7.724	1480.7	.15918	95.56	6876.71	216.29	12092.30
95.600	45000.0	99000.0	14083.9	14.984	11.004	2205.2	.22592	95.83	9781.26	217.00	19263.12
95.800	45000.0	99000.0	11725.0	24.860	15.982	3316.8	.32381	96.12	14238.72	217.98	32855.22
96.000	45000.0	99000.0	9233.6	41.792	23.486	4868.9	.45364	96.45	20909.61	221.05	58024.09



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	45000.0	99000.0	6630.0	68.108	33.542	6292.4	.56623	96.77	30301.77	231.06	97576.47

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
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APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	MOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	46000.0	99000.0	46000.0	.006	.007	.0	.00011	81.00	55.86	261.23	103.67
82.000	46000.0	99000.0	46000.0	.007	.007	.0	.00012	82.00	56.12	261.24	103.67
83.000	46000.0	99000.0	46000.0	.008	.008	.0	.00014	83.00	56.47	261.25	103.67
84.000	46000.0	99000.0	46000.0	.009	.009	.0	.00016	84.00	56.97	261.27	103.67
85.000	46000.0	99000.0	46000.0	.010	.011	.0	.00019	85.00	57.69	261.28	103.67
86.000	46000.0	99000.0	46000.0	.012	.013	.0	.00022	86.00	58.77	261.28	103.67
87.000	46000.0	99000.0	46000.0	.015	.016	.0	.00027	87.00	60.46	261.25	103.67
88.000	46000.0	99000.0	46000.0	.019	.020	.0	.00035	88.00	63.26	261.13	103.67
89.200	46000.0	99000.0	46000.0	.028	.029	.0	.00050	89.20	69.52	260.73	103.67
89.400	46000.0	99000.0	46000.0	.030	.031	.0	.00054	89.40	71.06	260.62	103.67
89.600	46000.0	99000.0	46000.0	.032	.033	.0	.00058	89.60	72.78	260.50	103.67
89.800	46000.0	99000.0	46000.0	.034	.036	.0	.00062	89.80	74.69	260.37	103.67
90.000	46000.0	99000.0	46000.0	.034	.039	.0	.00067	90.00	76.77	260.24	99.03
90.200	46000.0	99000.0	45960.9	.037	.042	.3	.00073	90.20	80.07	260.09	99.54
90.400	46000.0	99000.0	45843.7	.041	.046	.6	.00079	90.40	83.28	259.95	101.10
90.600	46000.0	99000.0	45648.2	.045	.050	.9	.00087	90.60	86.34	259.84	103.95
90.800	46000.0	99000.0	45374.6	.050	.055	1.3	.00096	90.80	89.24	259.66	107.78
91.000	46000.0	99000.0	45022.9	.055	.061	1.7	.00106	91.00	91.92	259.53	112.92
91.200	46000.0	99000.0	44592.9	.065	.068	2.7	.00139	91.20	99.09	257.18	119.35
91.400	46000.0	99000.0	44084.6	.073	.078	3.8	.00170	91.40	101.98	252.20	128.20
91.600	46000.0	99000.0	43498.3	.082	.088	4.3	.00175	91.60	114.96	249.85	139.49
91.800	46000.0	99000.0	42833.8	.094	.101	5.3	.00194	91.80	129.20	248.58	153.15
92.000	46000.0	99000.0	42091.2	.107	.115	6.7	.00219	92.00	134.23	247.56	170.34
92.200	46000.0	99000.0	41270.3	.124	.133	8.4	.00250	92.20	152.08	246.74	191.56
92.400	46000.0	99000.0	40371.3	.144	.155	10.5	.00288	92.40	172.69	246.07	217.80
92.600	46000.0	99000.0	39393.6	.176	.185	16.4	.00405	92.60	203.65	239.84	250.88
92.800	46000.0	99000.0	38338.0	.210	.222	19.8	.00456	92.80	233.38	236.32	294.60
93.000	46000.0	99000.0	37204.0	.254	.268	25.1	.00539	93.00	273.86	234.12	350.27
93.200	46000.0	99000.0	35991.7	.309	.326	32.4	.00649	93.20	324.92	232.56	421.47
93.400	46000.0	99000.0	34700.3	.390	.403	52.7	.00956	93.40	391.20	228.75	514.29
93.600	46000.0	99000.0	33330.5	.489	.508	61.8	.01075	93.60	478.88	224.74	640.33
93.800	46000.0	99000.0	31881.9	.621	.643	82.0	.01342	93.80	598.49	222.55	808.50
94.000	46000.0	99000.0	30354.0	.799	.822	110.4	.01705	94.00	755.45	221.08	1034.88
94.200	46000.0	99000.0	28746.0	1.049	1.068	154.1	.02243	94.20	976.69	218.97	1347.46
94.400	46000.0	99000.0	27057.8	1.391	1.400	212.0	.02925	94.40	1261.29	217.79	1782.17
94.600	46000.0	99000.0	25288.0	1.875	1.857	295.7	.03871	94.60	1664.09	217.00	2397.28
94.800	46000.0	99000.0	23435.1	2.575	2.494	417.5	.05196	94.80	2245.16	216.45	3287.78
95.000	46000.0	99000.0	21496.7	3.617	3.396	596.9	.07072	95.00	3057.55	216.07	4612.94
95.200	46000.0	99000.0	19469.4	5.215	4.690	865.1	.09768	95.20	4210.58	215.79	6655.35
95.400	46000.0	99000.0	17348.4	7.762	6.566	1258.7	.13566	95.40	5855.28	216.04	9923.79
95.600	46000.0	99000.0	15125.1	12.096	9.334	1867.8	.19205	95.60	8321.52	216.65	15514.13
95.800	46000.0	99000.0	12786.8	20.071	13.505	2785.8	.27349	95.80	11952.51	217.53	25828.30
96.000	46000.0	99000.0	10309.6	34.145	20.030	4371.0	.40736	96.00	17625.95	218.56	46843.95



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	46000.0	99000.0	7730.5	52.742	28.772	5280.4	.48081	96.68	25977.81	226.58	74578.41
	UNREFRACTED RAY STRIKES DISC										

## REFRACTION AIRMASS TABLES

## LATITUDE WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	47000.0	99000.0	47000.0	.005	.006	.0	.00010	81.00	48.93	261.62	90.84
82.000	47000.0	99000.0	47000.0	.006	.006	.0	.00011	82.00	49.16	261.64	90.84
83.000	47000.0	99000.0	47000.0	.007	.007	.0	.00012	83.00	49.47	261.67	90.84
84.000	47000.0	99000.0	47000.0	.008	.008	.0	.00014	84.00	49.91	261.70	90.84
85.000	47000.0	99000.0	47000.0	.009	.010	.0	.00016	85.00	50.54	261.72	90.84
86.000	47000.0	99000.0	47000.0	.011	.011	.0	.00020	86.00	51.49	261.75	90.84
87.000	47000.0	99000.0	47000.0	.013	.014	.0	.00024	87.00	52.97	261.74	90.84
88.000	47000.0	99000.0	47000.0	.017	.018	.0	.00031	88.00	55.42	261.65	90.84
89.200	47000.0	99000.0	47000.0	.024	.025	.0	.00044	89.20	60.91	261.24	90.84
89.400	47000.0	99000.0	47000.0	.026	.027	.0	.00047	89.40	62.26	261.12	90.84
89.600	47000.0	99000.0	47000.0	.028	.029	.0	.00051	89.60	63.77	260.98	90.84
89.800	47000.0	99000.0	47000.0	.030	.031	.0	.00055	89.80	65.45	260.83	90.84
90.000	47000.0	99000.0	47000.0	.030	.034	.0	.00059	90.00	67.28	260.66	86.60
90.200	47000.0	99000.0	46960.9	.032	.037	.2	.00064	90.20	70.17	260.48	87.05
90.400	47000.0	99000.0	46843.6	.036	.040	.5	.00076	90.40	72.98	260.30	88.42
90.600	47000.0	99000.0	46648.2	.039	.044	.8	.00084	90.60	75.66	260.11	90.91
90.800	47000.0	99000.0	46374.6	.043	.049	1.1	.00084	90.80	78.20	259.93	94.26
91.000	47000.0	99000.0	46022.7	.048	.054	1.5	.00093	91.00	80.55	259.76	98.75
91.200	47000.0	99000.0	45592.8	.054	.060	2.0	.00103	91.20	86.71	259.60	104.73
91.400	47000.0	99000.0	45084.6	.060	.067	2.5	.00115	91.40	89.04	259.45	112.01
91.600	47000.0	99000.0	44498.2	.071	.075	3.9	.00153	91.60	99.95	256.52	120.97
91.800	47000.0	99000.0	43833.5	.081	.087	4.9	.00177	91.80	112.22	251.14	132.83
92.000	47000.0	99000.0	43090.8	.093	.100	5.9	.00193	92.00	116.65	249.40	147.74
92.200	47000.0	99000.0	42269.9	.107	.115	7.3	.00219	92.20	132.24	248.11	166.14
92.400	47000.0	99000.0	41370.8	.125	.134	9.2	.00252	92.40	150.17	247.12	188.90
92.600	47000.0	99000.0	40393.4	.147	.157	11.6	.00293	92.60	171.17	246.32	217.15
92.800	47000.0	99000.0	39337.5	.181	.190	18.0	.00410	92.80	203.10	239.86	253.06
93.000	47000.0	99000.0	38203.5	.218	.230	21.9	.00469	93.00	237.33	236.26	300.83
93.200	47000.0	99000.0	36991.2	.265	.280	28.0	.00561	93.20	280.90	234.02	361.94
93.400	47000.0	99000.0	35700.5	.326	.343	36.5	.00682	93.40	336.53	232.43	440.74
93.600	47000.0	99000.0	34336.5	.416	.432	54.8	.00947	93.60	410.08	227.40	545.70
93.800	47000.0	99000.0	32882.2	.529	.549	70.5	.01154	93.80	512.40	224.06	688.56
94.000	47000.0	99000.0	31354.8	.679	.702	94.5	.01461	94.00	646.40	222.07	880.74
94.200	47000.0	99000.0	29747.7	.890	.909	137.2	.01986	94.20	833.71	220.21	1144.22
94.400	47000.0	99000.0	28660.6	1.178	1.194	181.0	.02500	94.40	1076.59	218.48	1509.87
94.600	47000.0	99000.0	26292.4	1.585	1.584	252.1	.03304	94.60	1419.81	217.45	2027.26
94.800	47000.0	99000.0	24442.0	2.170	2.126	355.5	.04431	94.80	1914.56	216.76	2771.43
95.000	47000.0	99000.0	22507.2	3.033	2.893	507.7	.06024	95.00	2574.86	216.27	3868.86
95.200	47000.0	99000.0	20485.1	4.348	3.991	734.6	.08310	95.20	3585.70	215.93	5541.91
95.400	47000.0	99000.0	18371.4	6.414	5.585	1071.6	.11574	95.40	4986.33	215.87	8190.39
95.600	47000.0	99000.0	16159.3	9.843	7.927	1585.1	.16347	95.60	7081.99	216.34	12609.21
95.800	47000.0	99000.0	13838.1	15.951	11.438	2358.5	.23247	95.80	10163.97	217.11	20502.10
96.000	47000.0	99000.0	11388.5	27.143	16.868	3663.8	.34362	96.00	14951.61	218.11	36329.88



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	47000.0	99000.0	8814.3	42.470	24.700	4569.5	.41899	96.62	22017.86	222.37	58963.43

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	48000.0	99000.0	48000.0	.005	.005	.0	.00009	81.00	42.86	262.08	79.59
82.000	48000.0	99000.0	48000.0	.005	.006	.0	.00010	82.00	43.07	262.11	79.59
83.000	48000.0	99000.0	48000.0	.006	.006	.0	.00011	83.00	43.34	262.14	79.59
84.000	48000.0	99000.0	48000.0	.007	.007	.0	.00012	84.00	43.72	262.19	79.59
85.000	48000.0	99000.0	48000.0	.008	.008	.0	.00014	85.00	44.27	262.24	79.59
86.000	48000.0	99000.0	48000.0	.010	.010	.0	.00017	86.00	45.10	262.29	79.59
87.000	48000.0	99000.0	48000.0	.012	.012	.0	.00021	87.00	46.40	262.33	79.59
88.000	48000.0	99000.0	48000.0	.015	.016	.0	.00027	88.00	48.55	262.30	79.59
89.200	48000.0	99000.0	48000.0	.021	.022	.0	.00039	89.20	53.36	261.94	79.59
89.400	48000.0	99000.0	48000.0	.023	.024	.0	.00042	89.40	54.54	261.80	79.59
89.600	48000.0	99000.0	48000.0	.024	.026	.0	.00045	89.60	55.87	261.64	79.59
89.800	48000.0	99000.0	48000.0	.026	.028	.0	.00048	89.80	57.34	261.46	79.59
90.000	48000.0	99000.0	48000.0	.026	.030	.0	.00052	90.00	58.94	261.25	75.73
90.200	48000.0	99000.0	47960.9	.028	.032	.2	.00057	90.20	61.48	261.02	76.13
90.400	48000.0	99000.0	47843.6	.031	.035	.4	.00062	90.40	63.94	260.77	77.32
90.600	48000.0	99000.0	47648.1	.034	.039	.7	.00067	90.60	66.30	260.53	79.35
90.800	48000.0	99000.0	47374.5	.038	.043	1.0	.00074	90.80	68.52	260.29	82.43
91.000	48000.0	99000.0	47022.6	.042	.047	1.3	.00081	91.00	70.58	260.07	86.36
91.200	48000.0	99000.0	46592.6	.047	.052	1.7	.00090	91.20	75.99	259.85	91.59
91.400	48000.0	99000.0	46084.4	.053	.058	2.2	.00101	91.40	81.40	259.65	97.96
91.600	48000.0	99000.0	45497.9	.060	.066	2.8	.00113	91.60	87.44	259.49	106.06
91.800	48000.0	99000.0	44833.3	.068	.074	3.9	.00140	91.80	97.55	258.82	115.81
92.000	48000.0	99000.0	44090.4	.081	.086	5.8	.00184	92.00	101.57	252.87	128.13
92.200	48000.0	99000.0	43269.4	.093	.100	6.5	.00194	92.20	114.93	250.03	144.09
92.400	48000.0	99000.0	42370.2	.108	.116	8.0	.00220	92.40	130.58	248.50	163.83
92.600	48000.0	99000.0	41392.8	.127	.136	10.1	.00255	92.60	148.86	247.36	188.34
92.800	48000.0	99000.0	40337.2	.150	.161	12.8	.00299	92.80	170.44	246.47	219.91
93.000	48000.0	99000.0	39202.9	.187	.196	19.6	.00418	93.00	206.37	239.50	258.40
93.200	48000.0	99000.0	37990.6	.227	.240	24.4	.00487	93.20	243.28	235.99	310.84
93.400	48000.0	99000.0	36699.9	.279	.295	31.5	.00590	93.41	290.81	233.77	378.46
93.600	48000.0	99000.0	35330.7	.347	.365	41.3	.00725	93.61	351.56	232.21	466.59
93.800	48000.0	99000.0	33882.1	.450	.468	61.2	.01001	93.81	438.80	226.22	586.37
94.000	48000.0	99000.0	32355.2	.578	.600	81.1	.01254	94.01	553.28	223.37	749.86
94.200	48000.0	99000.0	30748.9	.752	.775	110.1	.01609	94.22	712.66	221.57	971.84
94.400	48000.0	99000.0	29062.5	.999	1.018	155.2	.02143	94.42	919.09	219.40	1280.74
94.600	48000.0	99000.0	27295.8	1.342	1.351	215.1	.02822	94.63	1211.66	218.02	1716.38
94.800	48000.0	99000.0	25447.3	1.833	1.813	303.0	.03780	94.84	1633.06	217.13	2340.11
95.000	48000.0	99000.0	23515.6	2.551	2.465	432.2	.05135	95.05	2195.42	216.52	3253.63
95.200	48000.0	99000.0	21497.8	3.634	3.398	624.4	.07075	95.27	3054.73	216.10	4632.36
95.400	48000.0	99000.0	19390.3	5.325	4.753	914.9	.09897	95.50	4246.66	215.81	6792.66
95.600	48000.0	99000.0	17187.7	8.068	6.738	1347.3	.13930	95.74	6028.68	216.08	10323.62
95.800	48000.0	99000.0	14880.7	12.825	9.702	2001.1	.19791	96.00	8646.73	216.74	16464.61
96.000	48000.0	99000.0	12453.9	21.805	14.245	3082.6	.29065	96.29	12692.51	217.68	28437.56



# REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	PIEFF) (10)	TIEFF) (11)	PITAN) (12)
96.200	48000.0	99000.0	9888.0	35.579	21.214	4249.4	.38789	96.59	18831.54	219.06	48809.56
96.400	48000.0	99000.0	7201.2	65.408	31.246	6540.6	.56468	96.96	28077.37	228.32	93699.72

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

MIOLATITUDE WINTER  
ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMIC ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
81.000	49000.0	99000.0	49000.0	.004	.004	.0	.00008	81.00	37.55	262.60	69.74
82.000	49000.0	99000.0	49000.0	.005	.005	.0	.00008	82.00	37.72	262.64	69.74
83.000	49000.0	99000.0	49000.0	.005	.006	.0	.00010	83.00	37.96	262.69	69.74
84.000	49000.0	99000.0	49000.0	.006	.006	.0	.00011	84.00	38.29	262.76	69.74
85.000	49000.0	99000.0	49000.0	.007	.007	.0	.00013	85.00	38.77	262.84	69.74
86.000	49000.0	99000.0	49000.0	.008	.009	.0	.00015	86.00	39.50	262.94	69.74
87.000	49000.0	99000.0	49000.0	.010	.011	.0	.00019	87.00	40.63	263.05	69.74
88.000	49000.0	99000.0	49000.0	.013	.014	.0	.00024	88.00	42.51	263.12	69.74
89.200	49000.0	99000.0	49000.0	.019	.020	.0	.00034	89.20	46.71	262.93	69.74
89.400	49000.0	99000.0	49000.0	.020	.021	.0	.00037	89.40	47.75	262.81	69.74
89.600	49000.0	99000.0	49000.0	.021	.022	.0	.00040	89.60	48.91	262.64	69.74
89.800	49000.0	99000.0	49000.0	.023	.024	.0	.00044	89.80	50.20	262.42	69.74
90.000	49000.0	99000.0	49000.0	.023	.026	.0	.00048	90.00	51.61	262.15	66.23
90.200	49000.0	99000.0	48960.9	.025	.028	.2	.00051	90.20	53.84	261.84	66.57
90.400	49000.0	99000.0	48843.6	.027	.031	.4	.00055	90.40	56.01	261.49	67.61
90.600	49000.0	99000.0	48648.1	.030	.034	.6	.00060	90.60	58.09	261.14	69.38
90.800	49000.0	99000.0	48374.4	.033	.037	.9	.00065	90.80	60.04	260.81	72.09
91.000	49000.0	99000.0	48022.5	.037	.041	1.2	.00072	91.00	61.85	260.49	75.52
91.200	49000.0	99000.0	47592.4	.041	.046	1.5	.00080	91.20	66.58	260.20	80.10
91.400	49000.0	99000.0	47084.1	.046	.051	1.9	.00089	91.40	68.37	259.95	85.67
91.600	49000.0	99000.0	46497.6	.052	.058	2.4	.00099	91.60	76.63	259.72	92.75
91.800	49000.0	99000.0	45833.0	.059	.065	3.1	.00112	91.80	85.45	259.52	101.28
92.000	49000.0	99000.0	45090.1	.067	.074	3.9	.00127	92.00	88.71	259.35	111.95
92.200	49000.0	99000.0	44268.9	.081	.086	6.1	.00178	92.20	100.01	254.74	124.97
92.400	49000.0	99000.0	43369.6	.094	.101	7.1	.00196	92.40	113.49	250.45	142.09
92.600	49000.0	99000.0	42392.1	.110	.118	8.8	.00224	92.60	129.44	248.73	163.34
92.800	49000.0	99000.0	41336.4	.130	.140	11.1	.00261	92.80	148.22	247.47	189.86
93.000	49000.0	99000.0	40202.5	.155	.166	14.2	.00309	93.00	170.51	246.52	223.14
93.200	49000.0	99000.0	38589.8	.195	.206	21.6	.00430	93.20	211.33	238.88	266.99
93.400	49000.0	99000.0	37699.1	.240	.253	27.3	.00511	93.41	251.68	235.55	325.02
93.600	49000.0	99000.0	36330.0	.298	.314	35.6	.00626	93.61	303.65	233.42	400.47
93.800	49000.0	99000.0	34882.1	.375	.394	58.4	.00934	93.81	375.06	231.15	500.55
94.000	49000.0	99000.0	33355.1	.492	.511	69.9	.01081	94.01	473.73	225.13	638.67
94.200	49000.0	99000.0	31749.3	.640	.662	94.3	.01379	94.21	609.83	222.67	827.13
94.400	49000.0	99000.0	30064.0	.843	.866	129.4	.01793	94.42	784.51	221.06	1086.77
94.600	49000.0	99000.0	28298.1	1.137	1.152	183.8	.02413	94.62	1034.25	218.75	1454.63
94.800	49000.0	99000.0	26451.4	1.549	1.547	258.4	.03227	94.83	1393.29	217.60	1978.08
95.000	49000.0	99000.0	24522.1	2.149	2.102	368.1	.04379	95.04	1872.35	216.83	2741.88
95.200	49000.0	99000.0	22508.1	3.046	2.895	531.2	.06027	95.26	2572.55	216.31	3882.78
95.400	49000.0	99000.0	20406.0	4.436	4.044	776.9	.08419	95.48	3616.80	215.95	5651.18
95.600	49000.0	99000.0	18211.1	6.661	5.732	1147.0	.11884	95.72	5133.01	215.89	8502.83
95.800	49000.0	99000.0	15916.1	10.419	8.239	1701.0	.16870	95.97	7358.50	216.40	13345.05
96.000	49000.0	99000.0	13508.1	17.431	12.055	2601.6	.24638	96.25	10656.56	217.27	22427.00



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	MOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
96.200	49000.0	99000.0	10965.0	30.161	18.045	4057.6	.36642	96.57	16024.00	218.24	40874.20
96.400	49000.0	99000.0	8296.3	52.043	26.825	5742.1	.49801	96.90	23810.27	224.24	73583.39

UNREFRACTED RAY STRIKES DISC

## REFRACTION AIRMASS TABLES

## HORIZONTAL WINTER

ALL HEIGHTS ARE IN GEOMETRIC METERS  
ALL TEMPERATURES ARE IN DEGREES KELVIN  
ALL PRESSURES ARE IN N/SQ M  
THE APPARENT AND ASTRONOMICAL ANGLES ARE  
IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HOIFF (7)	REFRACTION (8)	AST. Z (9)	P(EFF) (10)	T(EFF) (11)	P(TAN) (12)
81.000	50000.0	99000.0	50000.0	.004	.004	.0	.00006	81.00	32.95	263.20	61.11
82.000	50000.0	99000.0	50000.0	.004	.004	.0	.00007	82.00	33.11	263.25	61.11
83.000	50000.0	99000.0	50000.0	.005	.005	.0	.00008	83.00	33.32	263.32	61.11
84.000	50000.0	99000.0	50000.0	.005	.006	.0	.00009	84.00	33.61	263.41	61.11
85.000	50000.0	99000.0	50000.0	.006	.007	.0	.00011	85.00	34.03	263.53	61.11
86.000	50000.0	99000.0	50000.0	.007	.008	.0	.00013	86.00	34.66	263.69	61.11
87.000	50000.0	99000.0	50000.0	.009	.009	.0	.00016	87.00	35.66	263.90	61.11
88.000	50000.0	99000.0	50000.0	.011	.012	.0	.00020	88.00	37.30	264.17	61.11
89.000	50000.0	99000.0	50000.0	.016	.017	.0	.00028	89.00	40.96	264.56	61.11
89.400	50000.0	99000.0	50000.0	.017	.018	.0	.00030	89.40	41.86	264.63	61.11
89.600	50000.0	99000.0	50000.0	.019	.020	.0	.00033	89.60	42.87	264.70	61.11
89.800	50000.0	99000.0	50000.0	.020	.021	.0	.00035	89.80	43.99	264.77	61.11
90.000	50000.0	99000.0	50000.0	.019	.023	.0	.00038	90.00	45.21	264.83	58.09
90.200	50000.0	99000.0	49960.9	.021	.025	.2	.00043	90.20	47.13	264.95	58.39
90.400	50000.0	99000.0	49843.6	.023	.027	.3	.00048	90.40	49.01	263.83	59.28
90.600	50000.0	99000.0	49648.0	.025	.030	.5	.00054	90.60	50.82	263.18	60.79
90.800	50000.0	99000.0	49374.3	.029	.033	.8	.00061	90.80	52.56	262.32	63.04
91.000	50000.0	99000.0	49022.3	.032	.036	1.1	.00069	91.00	54.18	261.20	66.04
91.200	50000.0	99000.0	48592.2	.036	.040	1.3	.00072	91.20	58.32	260.72	70.04
91.400	50000.0	99000.0	48083.8	.040	.045	1.7	.00080	91.40	59.89	260.35	74.92
91.600	50000.0	99000.0	47497.3	.046	.050	2.1	.00089	91.60	67.14	260.03	81.12
91.800	50000.0	99000.0	46832.5	.052	.057	2.7	.00100	91.80	74.89	259.77	88.57
92.000	50000.0	99000.0	46089.6	.059	.065	3.4	.00113	92.00	77.74	259.55	97.91
92.200	50000.0	99000.0	45268.4	.068	.074	4.2	.00129	92.20	87.42	259.36	109.35
92.400	50000.0	99000.0	44369.0	.081	.086	6.5	.00177	92.40	98.74	255.70	123.23
92.600	50000.0	99000.0	43391.3	.095	.102	7.9	.00199	92.60	112.50	250.66	141.67
92.800	50000.0	99000.0	42335.6	.113	.121	9.7	.00229	92.80	128.89	248.80	164.67
93.000	50000.0	99000.0	39989.2	.135	.144	12.3	.00270	93.00	148.29	247.48	193.53
93.200	50000.0	99000.0	38698.2	.162	.173	17.5	.00349	93.20	184.61	246.45	230.03
93.400	50000.0	99000.0	37329.1	.206	.217	23.9	.00448	93.40	218.39	238.08	279.15
93.600	50000.0	99000.0	35881.5	.256	.270	30.8	.00543	93.61	262.63	235.01	343.90
93.800	50000.0	99000.0	34354.6	.321	.338	40.6	.00673	93.81	323.49	232.99	429.02
94.000	50000.0	99000.0	32749.2	.419	.435	62.0	.00954	94.01	405.61	227.81	544.25
94.200	50000.0	99000.0	31064.5	.545	.565	81.0	.01186	94.21	522.04	224.12	704.26
94.400	50000.0	99000.0	29299.6	.717	.740	110.7	.01536	94.42	671.17	221.99	924.55
94.600	50000.0	99000.0	27454.3	.964	.982	157.9	.02074	94.62	882.95	219.76	1233.52
94.800	50000.0	99000.0	25527.0	1.311	1.319	220.5	.02757	94.83	1189.02	218.19	1674.60
95.000	50000.0	99000.0	23516.1	1.814	1.793	313.7	.03737	95.04	1597.22	217.21	2313.91
95.200	50000.0	99000.0	21418.7	2.560	2.467	452.2	.05138	95.25	2193.47	216.56	3263.71
95.400	50000.0	99000.0	19230.3	3.703	3.443	660.4	.07168	95.47	3081.53	216.11	4717.83
95.600	50000.0	99000.0	16945.3	5.521	4.877	978.6	.10156	95.70	4370.96	215.81	7039.21
95.800	50000.0	99000.0	14553.1	8.519	7.003	1448.2	.14397	95.94	6263.92	216.12	10898.48
96.000	50000.0	99000.0		13.933	10.219	2201.1	.20923	96.21	9066.20	216.90	17884.52



## REFRACTION AIRMASS TABLES

MIDLATITUDE WINTER  
 ALL HEIGHTS ARE IN GEOMETRIC METERS  
 ALL TEMPERATURES ARE IN DEGREES KELVIN  
 ALL PRESSURES ARE IN N/SQ M  
 THE APPARENT AND ASTRONOMICAL ANGLES ARE  
 IN DECIMAL DEGREES FROM THE ZENITH

THE WAVELENGTH FOR THIS TABLE IS 5.00 MICROMETERS.

APP. Z (1)	LOWER HEIGHT (2)	UPPER HEIGHT (3)	MIN. HEIGHT (4)	CHAPMAN AIR MASS (5)	OPTICAL AIR MASS (6)	HDIFF (7)	REFRACTION (8)	AST. Z (9)	P (EFF) (10)	T (EFF) (11)	P (TAN) (12)
96.200	50000.0	99000.0	12035.0	24.160	15.230	3432.0	.31137	96.51	13442.62	217.80	31922.39
96.400	50000.0	99000.0	9380.1	42.060	22.960	5062.2	.44046	96.84	20356.64	220.81	58388.44

UNREFRACTED RAY STRIKES DISC

## APPENDIX B. SOURCE STATEMENTS FOR THE RAY TRACING PROGRAM

The following listing is for the FORTRAN IV program used to calculate the values in Table 5. The calculations were performed on the BRLESC II computer, at the Ballistic Research Laboratories, which has a single precision accuracy of 16 significant digits. For use on other computers which carry fewer significant digits, the use of double precisions should be investigated.

The data deck consists of the following cards:

- Card 1. Title (13A6)
- Card 2. LEVELS (I5): the number of levels in the atmospheric profile to be read in.  
ALTORH (F5.0): variable defining input altitudes as geometric ( $\neq 0$ ) or geopotential ( $=0$ ) meters.  
ALAT (F10.8): latitude of the observer in degrees.  
NOPT (I10): format variable for the input profile.
- Card 3 to LEVELS + 2 input profile, altitude, temperature, and pressure (units depend on NOPT)
- Card LEVELS + 3: data card for specific geometry  
DD1 (F10.7) = zenith angle (degrees)  
DD2 (F9.6) = observer height (meters)  
DD3 (F10.6) = source height = highest level of profile (meters)  
DD4 (F11.3) = wavelength (micrometers)  
STOP (I4): program option parameter  
0 = Apparent zenith angle given - compute astronomical  
1 = Astronomical zenith angle given - compute apparent  
2 = calculate preceding case with new wavelength  
3 = call exit  
ALTORH (F8.1): parameter for geometric ( $\neq 0$ ) or geopotential ( $=0$ ) meters for observer height.

Any number of cards for specific geometries can be used (within time limit). To end the computation, the last data card should have a "3" in column 44.



MAXT ( 8. ) MINS.  
MAXO ( 8000 ) LINES

\*\*\*\*\* RAY TRACING PROGRAM \*\*\*\*\*

REFR0040

DIMENSION VARGCM(200)  
DIMENSION PTCRR ( 200 )  
DIMENSION P(200)  
DIMENSION H(200),T(200),GRAD(200),GAMMA(200)  
DIMENSION Z(200)  
DIMENSION THETAS(200)  
DIMENSION DELTH ( 200 )  
DIMENSION OMSTRAT(200)  
DIMENSION RHON(200),AIRS(200)  
DIMENSION ESTRAT(200),ESTR(200)  
DIMENSION RHC(200),ZRHON( 200 )  
DIMENSION XPTS(6),WGHTS(6)  
DIMENSION TITL(13)  
COMMON VARGCM

REFR0060  
REFR0140REFR0150  
REFR0280  
REFR0290  
REFR0300

1 RSTAR, (VARGCM(1),G), (VARGCM(2),AIRMT), (VARGCM(3),  
(VARGCM(4),RADIUS), (VARGCM(5),CONST1), (VARGCM(6),  
2 XPTS), (VARGCM(12),WGHT), (VARGCM(18),FAKE)

REFR0310  
REFR0320  
REFR0330

EQUIVALENCE (VARGCM(20),REFAM)  
EQUIVALENCE (WGHT,WGHTS)  
EQUIVALENCE (RHON,RHON)  
EQUIVALENCE (ESTRAT,ESTR)  
REAL IP

FCNA(Q000FL)=(1.0+Q000FL/2.0)\*(1.0+2.0+Q000FL\*(1.0+Q000FL/2.0)/3.0  
1)/(1.0+Q000FL)\*\*2  
FCNB(Q001FL)=2.0+Q001FL\*(1.0+Q001FL/2.0)/3.0  
FCNU(Q002FL,Q003FL,Q004FL,Q005FL)=2.0+Q004FL\*Q005FL/(1.0+Q005FL)  
103FL\*Q005FL  
FCNE(Q006FL,Q007FL)=Q006FL\*(1.0+Q007FL)\*(1.0+Q007FL\*Q006FL/6.0) REFR0390

FHC(X)=X\*RADIUS/(X+RADIUS)  
THIS FUNCTION CONVERTS GEOMETRIC METERS INTO GEOPOTENTIAL METERS  
FHC(X) = GPHI \* X/(RAD(US + X)  
FHC(Y) = RAD(US \* Y/(GPHI - Y )  
THIS FUNCTION CONVERTS GEOPOTENTIAL METERS INTO GEOMETRIC METERS

REFR0400  
REFR0410  
REFR0420  
REFR0500  
REFR0510  
REFR0440  
REFR0520  
REFR0530  
REFR0540  
REFR0550  
REFR0560  
REFR0570  
REFR0580  
REFR0590  
REFR0600  
REFR0610  
REFR0620  
REFR0630

NTAPAZ=5  
NERROR=6  
NTAPAZ=6  
NTAPAZ=6  
RADSEC=.206264856E+06  
RADCON=.174532925E+01  
FAKE=-1.0000000  
XPTS(1)=-.466234757E+00  
XPTS(2)=-.330604693E+00  
XPTS(3)=-.119309593E+00  
XPTS(4)=-.119309593E+00  
XPTS(5)=-.330604693E+00  
XPTS(6)=+.466234757E+00  
WGHTS(1)=-.856622491E-01  
WGHTS(2)=-.180380786E+00  
WGHTS(3)=-.233956967E+00  
WGHTS(4)=-.233956967E+00  
WGHTS(5)=-.180380786E+00  
WGHTS(6)=-.856622491E-01  
AVNFB = 5.02257 E26

REFR0640  
REFR0660  
REFR0650

```

C
C
C      READ ATMOSPHERE INFO
1000 READ (NTAPAZ,1021) (TITLE(I),I=1,13)
1021 FORMAT(13A6)
      READ (NTAPAZ,1025) LEVELS,ALTRH,ALAT, NOPT
1025 FORMAT(15,F5.0,F10.9, (10)
      PHI = ALAT * RADCON
      A = 6378160.0
      B = 6356775.0
      R = SQRT((A**4*(COS(PHI))**2 + B**4*(SIN(PHI))**2)/
      1 1 A**2*(COS(PHI))**2 + B**2*(SIN(PHI))**2))
      WRITE(6, 10) ALAT, R
10  FORMAT ( *1FOR A LATITUDE OF PHI = *, F6.2,3X*THE RADIUS OF THE
      1 SPHEROID IS R =*,F12.2,* METERS.*)
      X = COS(2.0 * PHI)
      Y = COS(4.0 * PHI)
      G*9.80665

```

REFR0460

```

C
C
C      THE FOLLOWING GEOPOTENTIAL FORMULAE WERE TAKEN FROM THE SMITHSON-
      IAN METEOROLOGICAL HANDBOOK.
      G = 980.6160 * ( 1.0 -( 0.0026373 * X ) + ( 0.0000059 *X**2))
      G = G/100.0
      PARTGZ = 3.085462 E-06 + 2.27 E-09 * X - 2.0 E-12 * Y
      RADIUS=6356766.0
      RADIUS = 2.0 * G / PARTGZ
      RADIUS = R
      RSTAR=8314.39
      AIRWT=28.966
      CONST1=G*AIRWT/RSTAR
      GEE = 9.80665
      GEE = 9.8

```

REFR0490

REFR0450  
REFR0470  
REFR0480

```

C
137
      GPHI = RADIUS * G / GEE
      WRITE ( 5,12 ) G, RADIUS, PARTGZ, GEE, GPHI
12  FORMAT ( * FOR THE GIVEN LATITUDE, THE FOLLOWING GEOPOTENTIAL INFO
      IMATION IS CALCULATED-* /// * G(PHI)=*, F15.8, / * R(PHI)= *, F15.5,
      2 / * PARTGZ =*, F15.8, / * GEE = *, F15.8, / * GPHI =*, F15.6 )
      GO TO ( 1050, 1060, 1050, 1050 ), NOPT
1050 READ(NTAPAZ,1075) (H(I),T(I),P(I),I=1,LEVELS)
1075 FORMAT(3F10.2)
      GO TO 1080
1060 READ(NTAPAZ,1085) (H(I),T(I),P(I),I=1,LEVELS)
1085 FORMAT ( F10.4, F10.6, E9.3 )
1080 CONTINUE
      GO TO ( 1, 2, 3, 4 ), NOPT
      NOPT = 1 MGLATCHEY'S PROFILES
      NOPT = 2 MET ROCKET NETWORK'S PROFILES
      NOPT = 3 MURKRAY'S RAWINDSONDE PROFILES
      NOPT = 4 1962 STANDARD ATMOSPHERE
      1 DO 6 I = 1, LEVELS
      IF ( 1.EQ.1 ) GO TO 5
      J = ( -1
      IF (H(J).LT.29.75 ) IF ( H(I) - 0.0 ) 101,102,101
      101 IF (H(J).LT.69.0 ) IF ( H(I) - 0.0 ) 103,104,103
      103 IF (H(J).LT.95.0 ) IF ( H(I) - 0.0 ) 105,106,105
      105 CONTINUE
      GO TO 5
102 H(I) = H(J) + 0.25
      GO TO 5
104 H(I) = H(J) + 1.0
      GO TO 5

```



```

106 H(I) = H(J) + 5.0
5 CONTINUE
IF ( T(I).EQ.0.000 ) T(I) = T(I-1)
T(I) = 272.344
C
6 CONTINUE
DO 107 I = 1,LEVELS
H(I) = H(I) + 1000.
107 CONTINUE
GO TO 1051
2 DO 7 I = 1, LEVELS
H(I) = H(I) + 10.0
T(I) = T(I) + 273.15
P(I) = P(I) + 100.0
7 CONTINUE
GO TO 1051
3 DO 8 I = 1, LEVELS
H(I) = H(I) + 0.5048
T(I) = T(I) + 273.15
P(I) = P(I) + 10.0
8 CONTINUE
GO TO 1051
4 DO 111 I = 1,LEVELS
H(I) = H(I) + 10.0
111 CONTINUE
1051 CONTINUE
C
C
C OBTAIN PRESSURE PROFILE
C
IF(P(1).EQ.0.1) P(1) = 101325.0
DO 1090 I = 2,LEVELS
CALL GETT(H(I-1),P(I-1),P(I),T(I-1),T(I))
1090 CONTINUE
IF(ALTGRH) 1100,1150,1100
1100 CONTINUE
C
C
C CONVERT TO GEOPOTENTIAL
C
DO 1125 I = 1,LEVELS
H(I) = FHC(H(I))
1125 CONTINUE
1150 CONTINUE
C
C
C COMPUTE GRADIENT AND RATIO OF SPECIFIC HEATS
C
DO 1175 I = 2,LEVELS
GRAD(I-1) = (T(I) - T(I-1)) / (H(I) - H(I-1))
GAMMA(I-1) = (CONST1) / (GRAD(I-1) + CONST1)
DELTH(I-1) = H(I) - H(I-1)
1175 CONTINUE
GAMMA(LEVELS) = 1.0
GRAC(LEVELS) = 0.0
DELTH(LEVELS) = 0.0
C
C
C COMPUTE ASSORTED STRATA (INFORMATION -- IN PARTICULAR
C COMPUTE THE DENSITY AT EACH BREAK POINT (ASSUMING SEA
C LEVEL AS ONE) AND THE OPTICAL AIR MASS ACROSS EACH STRATA
C (CUMULATIVE FROM ABOVE)
C
SUMRHO = 0.0
DO 1192 I = 1,LEVELS

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REFR071C
REFR0720
REFR0730
REFR0740
REFR0750
REFR0760
REFR0780
REFR079C
REFR0800
REFR0810
REFR0820
REFR0830
REFR0840
REFR0850
REFR0860
REFR0870
REFR0880
REFR0890
REFR0900
REFR0910
REFR0920

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ZRHON(I) = AVNMP * P(I) / (RSTAR * Y(I))
SUMRHC = SUMRHO + ZRHON(I) * DELT( I )
1190 CONTINUE
      ZRHON(I) = ZRHON(I)
      C OMSTRG WILL BE USED LATER TO CALCULATE THE INDEX OF REFRACTION
      C OF THE FIRST LAIR
      OMSTRO = 1.0 - ( RHCN(I) / 2.5475521 E25 )
      DO 1200 ( =2,LEVELS
      CALL OM (H(I),H(I-1),H(I-1),T(I-1),GAMMA(I-1),GMEGA,DUMPY)
      NLC=(-1
      OMSTRALNC)=GMEGA
      C COMPUTES DENSITY
      RHON(I)=RHON(I-1)*(1.0-GMEGA)
      C COMPUTES AIRMASS
      CALL OPT(H(I-1),H(I),T(I-1),GAMMA(I-1),RHO(I-1),OMEGA,AIRS(I-1)
      1)
1200 CONTINUE
      AIRS(LEVELS)=0.)
      DO 1225 I=2,LEVELS
      IND=LEVELS+1-I
      AIRS(IND)=AIRS(IND)+AIRS(IND+1)
1225 CONTINUE
      STARD = AIRS(I)
      C THIS CARD NORMALIZES ALL AIR MASSES TO THE 1962 US STANDARD ATM.
      REFAM = AIRS (I)
      C REFAM = 2.15235 E29
      C WRITE (6,100) REFAM ,STARD, SUMRHO
      C WRITE (6,100) REFAM ,STARD
100 FORMAT ( * THE REFERENCE AIRMASS IS *, E20.8, * MOLECULES /M2*,//
1,* FOR THIS PROFILE, THE INTEGRATED AIRMASS IS *,E20.8)
1,* FOR THIS PROFILE, THE INTEGRATED AIRMASS IS *,E20.8,/ * AND
2THE SUMMED AIRMASS IS *, E20.8, * MOLECULES/SQUARE METER*,//)
      C
      C COMPUTATIONS NECESSARY FOR INITIAL SET UP HAVE
      C BEEN COMPUTED. THE MODEL ATMOSPHERE HAS BEEN
      C ACCEPTED. THE NEXT PORTION OF THE PROGRAM IS
      C THE SOLUTION OF THE BASIC PROBLEM
      C
      WRITE(NTAP3,1231) (TITLE(I),I=1,10)
1231 FORMAT(1H,5X,25HREFRACTION AIRMASS TABLES,5X,10A6,/,2X)
      WRITE(NTAP3,1239) LEVELS
1239 FORMAT(1H,6X,7HLEVELS=,15,//
17X,36HTHE ATMOSPHERE PROFILE IS AS FOLLOWS,///,
21X,11HBREAK POINT,5X,15HTEMPERATURE (K),7X,13HPRESSURE ,12X,
3BHGRADIENT,5X,23HRATIO OF SPECIFIC HEATS,4X17HDENSITYMOL/M**3),/)
      C 21X,11HBREAK POINT,5X,15HTEMPERATURE (K),7X,13HPRESSURE (HG),12X,
      C 3BHGRADIENT,5X,23HRATIO OF SPECIFIC HEATS,//)
      DO 1242 (E=1,LEVELS
      C PTORR ( IE) = 0.0075 * P (IE)
      C PTORR I IE) = P (IE)
      C WRITE ( 6,1241 ) H(IE), T(IE), PTORR (IE), GRAD (IE), GAMMA (IE),
      1 ZRHON (IE)
      C 1RHON (IE), ZRHON (IE)
      C1241 FORMAT ( 1H, F10.4, 2F20.4, 2F20.8, E20.8 )
      C1241 FORMAT ( 1H, F10.4, 2F20.4, 2F20.8, E20.8 )
      C1241 FORMAT ( 1H, F10.4, 2F20.4, 2F20.8, E25.8 )
      C1241 FORMAT ( 1H, F10.4, 2F20.4, 2F20.8, 2E12.3 )
      C1241 FORMAT(1H,10X,3F20.4,2F20.8)
1242 CONTINUE
      WRITE(6,1243)

```

REFR0940  
REFR0950

REFR0970

REFR0980  
REFR0990  
REFR1000  
REFR1010  
REFR1020  
REFR1030  
REFR1040  
REFR1050

REFR1060  
REFR1070  
REFR1080  
REFR1090  
REFR1100  
REFR1110



```

1243 FORMAT(1F1)
    LINC=-1
1250 READ (NTAP2,1255) DD1,DD2,DD3,DU4,LSI:P,ALTD:RH
1255 FORMAT ( F10.7 , F9.6 , F11.6 , F11.3 , 14 , F8.1 )
C      DD3=DD3*-000.2
C      CD4 = 50.0
C      CD4 = CD4 * 100.1
C      JMP=LST3P+1
C      NTF=C
C      LINC=-1
C
C      JMP=1 IS BASIC REFRACTION PROGRAM
C      JMP=2 FIND Z SUCH THAT F-UND ZJ +R = READ ZC
C      JMP=3 USE OLD ZC, HGHT, AND HGT AND NEW WAVELENGTH
C      JMP=4 CALL EXIT
C      JMP=5 READ NEW PROFILE
C
C      GO TO (1257,1257,1258,1256,12CC), JMP
C      1256 GO TO 1400
C1257 ZO=DD1
1257 DO 4150 IN= 1,5
    IF ( DD1 .LT. 89.0) DD1 = DD1 + 1.0
    IF ( DD1 .LT. 89.0) GO TO 1297
    CD1 = DD1 + 0.2
1297 CONTINUE
    ZO=CD1
    ZOS=ZO
    DHGHT=DD3
    HGHT=CD4
1258 WAVELENGTH=DD2
    ZO=ZOS
1270 IF (ALTGRH) 1280,1290,1280
1280 OHGHT=FHC(DHGHT)
    HGHT =FHC(HGHT)
1290 CONTINUE
    ZO=ZO
    ZT=ZOS
1295 CONTINUE
    NTF=NTF+1
    IF (NTF-10) 1296,1296,4700
1296 CONTINUE
    SECT2=0.
    SECT3 = 0.0
    SECT4 = 0.0
    RSARE=0.
    DSARE=0.
    TSARE = 0.0
    HDIFF = 0.0
    HTAN = 0.0
    TP = TG = 273.15
C      Z IS IN DEGREES - CONVERT TO RADIANS
C
C      ZO=ZO*RADCON
C      UTEMP=1./WAVELENGTH
C
C      COMPUTE E1 FROM EDLENS FORMULA
C      E1 = 0.7

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E1=.00064328+.0204981/I146.-UTEMP)+.0012554/(41.C-UTEMP)
      C    COMPUTE THE REFERENCE AIR MASS
      A. FIND THE STRATA NUMBER OF J
      B. COMPUTE M FOR REMAINDER OF STATUM
      C. ADD IN AIR ABOVE THAT STATUM
REFR1230
REFR1240
REFR1250
REFR1260
REFR1270
REFR1280
REFR1290
REFR1300
REFR1310
REFR1320
REFR1330
REFR1340
REFR1350
REFR1360
REFR1370
REFR1380
REFR1390
REFR1400
REFR1410
REFR1420
REFR1430
REFR1440
REFR1450
REFR1460
REFR1470
REFR1480
REFR1490
REFR1500
REFR1510
REFR1520
REFR1530
REFR1540
REFR1550
REFR1560
REFR1570
REFR1580
REFR1590
REFR1600
REFR1610

      FIND INDEX FOR ATMOSPHERIC SHELL OF THE ABSORBER
DO 1300 IHT=2,LEVELS
IF(IH(IHT)-DHGHT) 1300,1325,1325
1300 CONTINUE
      CALL CUMP
1325 IHT=IHT-1
      RHOP = ZRHON ( IHT )
      POB = P I IHT ) * 0.0C75
      THE FOLLOWING STATEMENTS INTERPOLATE FOR PRESSURE AND DENSITY
      CALL GETT ( PIHT), DHGHT, PIHT), POB, TIHT), T(IHT) )
      RHOP = AVMB + POB/ RSTAR * TIHT )
      RHOIN = RHOP
      POB = POB * G.OC75
      TP = T I IHT )
      FIND INDEX FOR ATMOSPHERIC SHELL OF SOURCE
DO 1335 IND= 2 ,LEVELS
      JHT=IND
      IF(IH(JHT)-HGHT) 1335,1340,1340
1335 CONTINUE
      WRITE (INERRR,1337)
1337 FORMAT(2'H UPPER HEIGHT RESET)
1330 JHT=IND
1340 CONTINUE
      C
      C    COMPUTE Z AT EACH STRATUM LINE
      C
      C    FIND E AT EACH LAYER ISUPHSTIGATE LATER)
      C    THE PERCENT METHOD ASSUMES AN ATMOSPHERE I OF CONSTANT
      C    COMPOSITION AND CALCULATES THE REFRACTIVE INDEX FROM THE LORENTZ-
      C    LORENTZ FORMULA
      C
      C    THE VALUE OF THE INDEX OF REFRACTION FOR THE FIRST LAYER IS CAL-
      C    ULATED FROM THE VALUE AT STP. I T = 15 DEG C AND P = 760 TORR
      C    ESTRAT II) = FCNE ( E1 , DMSTRUC )
      C    DO 1350 I=2,LEVELS
      C    ESTRAT(I)=FCNE(ESTRAT(I-1),MSTRAT(I-1))
1350 CONTINUE
      C
      C    COMPUTE FIRST 2S AND THETAS
      C
      C    NEW SECTION TO HANDLE ALL GEOMETRIES
      C
      C    JNS=1
      C
      C    HMINA=DHGT
      C    IF (ZOS.LE.99.) IF IHGHT-DHGT+.05) 4500,4600,1373
      C
      C    CASE 1. GO TO 1373 ( BASIC PROBLEM )
      C    CASE 2. GO TO 4600 ( TRIVIAL CASE )
      C    CASE 3. GO TO 4500 ( NO SOLUTION )
      C
      C    NOT BASIC PROBLEM

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C THE FOLLOWING SECTION IS USED TO DETERMINE WHETHER THE LIGHT RAY
C IS OF TYPE 1, 2, OR 3.
C
C CALL OM(CHGHT,H(IHT),H(IHT),T(IHT),GAMMA(IHT),OME,XXX)
EO=FCNE(ESTRAT(IHT),OME)
C
C ZLCR(TICAL) IS THE ANGLE OF A TANGENT RAY TO THE SURFACE OF THE EARTH
C
C ZCR(I) = ASIN ((1.0 + ESTR (I) ) * ( 1.0 - CHGHT / RADIUS ) / ( 1.0
1 + EJ ))
C ZCR(I)=3.141592653-ZCR(I)
C CASE 4 GO TO 4500
C CASE 5. GO TO 1357
C CASE 2. GO TO 4600
C IF (Z0.GT.ZCR(I)+.0001) IF(CHGHT-HGHT+.5) 4500,4600,1357
C THIS SECTION CALCULATES FOR A GRAZING RAY THAT DOES NOT
C INTERSECT THE SURFACE OF THE EARTH ( I.E. CASES 1 THRU 9
C
C COMPUTE HM ( THE TANGENT OR MIN(MUM HE(GHT)
C
FVAL =SIN(Z0)*(1.+EO)/(RADIUS-CHGHT)
F1=(1.+ESTR(1))/RADIUS - FVAL
DO 1351 I=2,LEVELS
K=(-1)
F2=(1.+ESTR(I))/(RAD(US-H(I))-FVAL
(F1F2*F1) 1352,1352,1351
1351 F1=F2
GO TO 4500
1352 H1=H(K)
H2=H(K+1)
H3=H1-(H2-H1)*F1/(F2-F1)
1353 CALL OM( H3,H(K),H(K),T(K),GAMMA(K),W,XXX)
F3=(1.+FCNE(ESTRAT(K),W))/(RADIUS-H3)-FVAL
HM=H3-F3*((H3-H2)/(F3-F2)+(H3-H1)/(F3-F1)-(H2-H1)/(F2-F1))
IF(ABS(HM-H3).LE.1.) GO TO 1354
H1=H2
H2=H3
H3=HM
F1=F2
F2=F3
GO TO 1353
1354 IF (HM.GT.HGHT+.05) GO TO 4500
C
C Z0 = 90 DEGREES, AND THE FOLLOWING SECTION CALCULATES FROM THE MINIMUM
C POINT TO THE OBSERVER
C
C PMINA=HM
ZOSAVE=70
HOSAVE=7/HGHT
HSSAVE=HGHT
Z0=1.570796326
OHGHT=HM
HGHT=HOSAVE
C THE FOLLOWING INTERPOLATES FOR TANGENT HE(GHT) PRESSURE AND DENSITY
C CALL GETT ( H(K), HM, P(K), PCB, T(K), T(K) )
C RHOMIN = AVNMB * PCB / ( RSTAR * T(K) )
C POB = P28 * 0.0075
C POB = P(K) * 0.0075
C RHOH(N = ZRHOH ( K )
TG = T ( K )

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```

JSAB=JHT
JHT=(JHT+1)
JHT=K
INS=2
GO TO 1374
C HAVING JUST COMPLETED FROM THE TANGENT HEIGHT TO THE OBSERVER, WE NOW
C GO FROM TANGENT HEIGHT TO X-CURVE
1355 JSAB=REFRS
JSAB=SECT2
PSAVE = SECT3
TSAB = SECT4
HGT=HSSAVE
JHT=JSAB
INS=3
GO TO 1374
C
C
C (IF THE SOURCE IS LOWER THAN THE OBSERVER FOR Z GREATER THAN 90 DEG.
C THERE EXIST 2 POSSIBLE SOLUTIONS TO THE PROBLEM
C
1356 IF(HSSAVE.LT.HOSAVE) JNS=2
OHGHT=HOSAVE
GO TO 3950
C
C
C START HERE FOR CASE 5 ( TYPE U RAY AND HS LESS THAN HC
C
1357 CALL OM(HGHT,H(JHT),H(JHT),T(JHT),GAMMA(JHT),W,XXX)
ZSAVE=AS(N(1.+EQ)/11.+FCNE(ESTR(JHT),W))*(RADIUS-HGHT)/(RADIUS-
10HGHT))
JHT=JHT
Z=Z0
Z=Z0
Z=ZSAVE
HOSAVE=OHGHT
HSSAVE=HGHT
OHGHT=HSSAVE
HGHT=HOSAVE
Z=Z
INS=4
GO TO 1374
1358 JNS=1
OHGHT=HOSAVE
HGHT=HSSAVE
GO TO 3950
1373 INS=1
1374 CONTINUE
CALL OM(OHGHT,H(JHT),H(JHT),T(JHT),GAMMA(JHT),OME,DUMMY)
CALL OM(H(JHT+1),HGHT,H(JHT),T(JHT),GAMMA(JHT),CNO,TOO)
EO=FCNE(ESTR(JHT),OME)
VARCOM(19)=RFO((JHT)*11.-OME)
(F(JHT,EO,JHT+1) GO TO 1380)
US=FCNU(FCNA(EO),FCNR(EO),EO,CML)
CALL ZCOMPL(Z,(JHT+1),OHGHT,H(JHT+1),US,DELZ,THETAS(JHT+1)
1)
CALL QUAD(THETAS(JHT+1),ZC,HGHT,TOO,P(JHT+1),GAMMA(JHT),EO,SECT1,
1SECT2,SECT3,SECT4)
REFR=(DELZ+SECT1)
REFRS=REFR+RADSEC
2010 DELRS=REFRS
C
C
C COMPUTE SUCCEEDING Z'S
C
REFR1660
REFR1670
REFR1680

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```

2000 INDU=JHT-2
    IHT1=IHT+1
    IF IINDU.LT.IHT1) GO TO 1376
1360 CONTINUE
    DO 1375 I=IHT1,IHTU
        *****
        U=FCNUIFCNA(ESTR(I)),FCNB(ESTR(I)),ESTR(I),CMSTRA(I))
        CALL ZCOMP(Z(I),Z(I+1),P(I),H(I),P(I),GAMMA(I),ESTR(I),ADD1,
1)
        DELZ=DELZ+CELZ
        VARCOM(19)=RPO(I)
        CALL QUACITHTAS(I+1),Z(I),H(I),P(I),GAMMA(I),ESTR(I),ADD1,
1)ADD2,ADD3,ADD4)
        SECT2=SECT2+ACD2
        SECT3 = SECT3 + ADD3
        SECT4 = SECT4 + ADD4
        DELR =(DELZ+ADD1)
        REFR =DELZ+REFR
        REFRS=REFR*ACDSEC
        DELD=DELZ*ACDSEC
1375 CONTINUE
1376 CONTINUE
        ROLAST=RHQ(JHT-1)
        ZLAST=Z(JHT-1)
        ELAST=ESTR(JHT-1)
        PLAST = P(JHT - 1)
        TLAST=TI(JHT-1)
        GLAST=GAMMA(JHT-1)
        HLAST=H(JHT-1)
1377 CONTINUE
        CALL OH(HGHT,HLAST,H(JHT-1),TLAST,GLAST,CLAST,XXX)
        U=FCNUIFCNA(ELAST),FCNB(ELAST),ELAST,GLAST)
        CALL ZCOMP(ZLAST,ZF(N,HLAST,HGHT,U,DELZ,THFIN)
        VARCOM(19)=ROLAST
        CALL QUACITHTFIN,ZLAST,HLAST,TLAST,PLAST,GLAST,ELAST,ADD1,ADD2,ADD3
1)ADD4)
        SECT3 = SECT3 + ADD3
        SECT4 = SECT4 + ADD4
        DELR=DELZ+ADD1
        REFR=DELZ+REFR
        REFRS=REFR*ACDSEC
        SECT2=SECT2+ADD2
        DELD=DELZ*ACDSEC
        IF IINS.EQ.2) GO TO 1355
        KJHT=JHT-1
        GO TO 1395D,1355,1356,1358),(INS
        CALCULATES WHEN YOU GET TO THE LAST LEVEL
1380 ROLAST=VARCOM(19)
        ZLAST=ZJ
        ELAST=EL
        HLAST=OHGHT
        TLAST=TI(JHT-1)
        PLAST = P(JHT - 1)
        GLAST=GAMMA(JHT-1)
        REFR=Q.
        GO TO 1377
3950 CONTINUE
        SECT3 = SECT3 + PSAVE

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```

C
  SECT4 = SECT4 + ISAVE
  REFRS=REFRS+RSAVE
  SECT2=SECT2+USAVE
  DERF=REFRS/3600.
  ZEND=ZUS+DERF
  PEFF = SECT3/SECT2 * 0.0075
  PEFF = SECT3/SECT2
  TEFF = SECT4/SECT2
C
  THIS DOES THE CALCULATION WHEN YOU START FROM THE AST. ZENITH ANG.
  IF (JMP.EQ.2) GO TO 4100
3980 CONTINUE
  IF (LINC) 3990,3999,3999
3990 WRITE (NTAP3,3991) TITLE
3991 FORMAT(1H1,5X25HREFRACTION AIRMASS TABLES,5X13A6,/,
390X38HALL HEIGHTS ARE IN GEOMETRIC METERS /,40X,*ALL TEMPERATUR
3ES ARE IN DEGREES KELVIN*/,40X,*ALL PRESSURES ARE IN N/SQ M */
440X40THE APPARENT AND ASTRONCM(CAL ANGLES ARE/
540X34HIN DECIMAL DEGREES FROM THE ZENITH/)
  WRITE ( 6 , 3993 ) WAVELENGTH
3993 FORMAT ( 40X *THE WAVELENGTH FOR THIS TABLE IS *,F5.2,* MICROMETER
1S.*//)
  WRITE(6,3992)
3992 FORMAT(11X5HLOWER,5X5SHUPPER,5X4HMIN., 7 X7HCHAPMAN , 5X7HOPTICAL)
  WRITE(6,3995)
C3995 FORMAT(1X6HAPP. 2,4X6HHEIGHT,4X6HHEIGHT,4X6HHEIGHT,3X8HHAIR MASS,4X
3995 FORMAT(1X6HAPP. 2,4X6HHEIGHT,4X6HHEIGHT,4X6HHEIGHT,5X8HHAIR MASS,4X
18HA(R MASS,4X5HDIFF,3X10HREFRACTION, 4X6HAST. 2,6X 6HP(EFF),4X6H
1T0EFF),6X6HP(TAN) )
  WRITE(6,3996)
C3996 FORMAT(3X3H(1),7X3H(2),7X3H(3),7X3H(4),7X3H(5), 8X3H(6),7X3H(7),
1 9X3H(8),9X3H(9),9X4H(10),6X4H(11), 8X4H(12) ,/,1X )
C
3996 FORMAT(3X3H(1),7X3H(2),7X3H(3),7X3H(4),8X3H(5), 8X3H(6),10X3H(7),
1 6X3H(8),9X3H(9),9X4H(10),6X4H(11), 8X4H(12) ,/,1X )
  LINC=42
3999 LINC=LINC-1
  ZFIN = ZEND * RADCON
  OHGHT = FZC ( OHGHT )
  HGHT = FZC ( HGHT )
  HMINA = FZC ( HMINA )
  SCALHP = RSTAR * TP / AIRWT / G
  XP = ( RADIUS + JHGHT ) / SCALHP
  WHY = SQR ( 0.5 * XP ) * ABS ( COS ( ZFIN ) )
  PERF = EXP((WHY)**2.0) * ( 1.0 - ERFN( WHY) )
  IF ( ZEND.LE. 70.0 ) GO TO 4035
  IF ( ZEND.LE. 90.0 ) GO TO 4030
C
  THE FOLLOWING COMPUTES THE CHAMAN FUNCTION FOR THE OPTICAL PATH
  OF A GRAZING RAY.
C
  THE FOLLOWING EXPRESSION CALCULATES THE TANGENT HEIGHT FOR THE
  CASE OF NO REFRACTION.
  HTAN = ( RADIUS + OHGHT ) * SIN ( ZFIN ) - RADIUS
  IF ( HTAN.LE. 0.0 ) GO TO 4002
  HDIFF = HMINA - HTAN
  DO 4000 JND = 2,LEVELS
  L = JND
  IF ( H(L) - HTAN ) 4000,4001,4001
4000 CONTINUE
  WRITE (6,1337)
4001 L=JND-1
  TG = T(L)
  CALL GETT ( F(L),HTAN,P(L), PCB, T(L), T(L) )

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RHOIN = AVNB * PCB / ( RSTAR * T(L) )
SCALHG = RSTAR * TG / AIR * I / G
XB = ( RADIUS + HMINA ) / SCALHG
WHY2 = SURT ( 1.570796326 * XG )
IP = WHY2 * SCALHG * ( 2.C * RHOIN - RHOIN * FERF )
GO TO 4040
4030 CONTINUE
C THE FOLLOWING COMPUTES THE CHAMAN FUNCTION FOR THE OPTICAL PATH
C WHICH IS NOWHERE TANGENT TO THE SURFACE OF THE EARTH
WHY1 = SCRT ( 1.570796326 * XP )
IP = RHOIN * SCALHG * WHY1 * FERF
GO TO 4040
4035 IP = A(RS((HT)/COS(ZFIN))
4040 CONTINUE
IP = (P/ REFAM
WRITE (INTAP3,4089) ZOS,CHGHT,HGHT,HM(NA, (P ,SECT2,HDIFF,DERF,
1ZEND ,PEFF, TEFF, P0H
4089 FORMAT(IX,F7.3,F10.1,F11.3, F11.3,F12.1 ,F11.5, F12.2, F12.2,
1F9.2, F12.2 )
4150 CONTINUE
GO TO (1250,4100,1250,1256,1000),JMP
4100 CONTINUE
IF(ABS(ZT-ZEND).LT..0001) GO TO 4200
ZOS=ZT-DERF
Z0=ZOS
GO TO 1295
4200 JMP=1
GO TO 3980
4500 WRITE(INTAP3,4510) ZOS
C4500 WRITE(INTAP3,4510) ZOS,CHGHT,HGHT,WAVEL
4510 FORMAT(IXF14.5, 60X2CH *** NO SOLUTION ***)
LINC=LINC-1
GO TO 1250
C THIS HANDLES THE CASE 2 WHEN SRCCE AND OBSERVER ARE CLOSE TOGETHER IN SAME
C SHELL
4600 REFRS=0.
SECT2=0.
SECT3 = 0.
SECT4 = 0.
GO TO 3950
4700 IF(ABS(ZT-ZEND).LT..001 ) GO TO 4200
LINC=LINC-2
WRITE INTAP3,4709) ZOS,CHGHT,HGHT,HM(NA,WAVEL,SECT2,REFRS,DERF,
1ZEND
WRITE (INTAP3,4705)
4705 FORMAT(1H ,37H***NO GOOD SOLUTION FOR LINE ABOVE***)
4802 WRITE (6,4003)
4803 FORMAT ( 1H * UNREFRACTED RAY STRIKES DISC * )
GO TO 1250
1400 CONTINUE
STOP
ENC
SUBROUTINE DUMP(XKEY)
XNEY=0.0
RETURN
END
FUNCTION ERFN(X)
X1=ABS(X)
X2=X1*X1
(FIX1.GT..47)GO TO 2

```

```

**** 1
ERFN 2
ERFN 3
ERFN 4

```

```

11 AL=(((-.0356098437C1815385+X2+6.5963P34886191355)*X2
12 1+21.979201618294152)*X2+242.6675523^53175
13 A2=((X2+15.082797637047787)*X2+91.164905404514901)*X2
14 1+215.0598758698612
15 A1=X1*A1/A2
16 GOTO 4
17 2 IF(X1-GT.4.)GOTO 3
18 A1=(((((1.368648573827167667E-7)*X1+.5641955174789739711)*X1
19 1+7.2117582508830933659)*X1+.433.16222722205673530)*X1
20 2+152.98928504694740391)*X1+339.3208167343436870)*X1
21 3+451.91895371187294221)*X1+360.4592610201616005
22 A2=(((((X1+12.78272731962942)*X1+77.00015293522947295)*X1
23 1+277.5854467439876434)*X1+638.9802644656311665)*X1
24 2+931.3540948506796211)*X1+790.9599253278980272)*X1
25 3+300.4592609569832933
26 A1=1.-EXP(-X2)*A1/A2
27 GOTO 4
28 3 X3=1./A2
29 A1=(((.0223192459734184686*X3+.278661308609647788)*X3
30 1+.226956593539686930)*X3+.0494730910623250734)*X3
31 2+100299610707703542174
32 A2=((((X3+1.987332C1817135256)*X3+1.05167510706793207)*X3
33 1+.191308926107829841)*X3+.036209230528467918
34 A1=1.-EXP(-X2)/X1*(.56418958354775627-X3*A1/A2)
35 4 IF(X-LT.0.)A1=-A1
36 ERFN=A1
37 RETURN
38 END
39
40 SUBROUTINE OM(H,HC,HN,TN,GAMMA,OMEGA,TO)
41 SUBROUTINE TO COMPUTE OMEGA
42 HN IS A BASE HEIGHT FOR THE LEVEL
43 HQ IS THE LOWER HEIGHT
44 H IS THE UPPER HEIGHT
45 OMEGA IS FROM THE LOWER HEIGHT 'T' THE UPPER HEIGHT
46
47 DOUBLE PREC(S ON Y,ONEG
48 COMMON G , AIRWT , RSTAR , RADIUS , CONST1
49 GM=ABS(GAMMA)
50 IF(GM-LT.0.)GO TO 801
51 ONEG=1.0-GAMMA
52 OMG=ONEG
53 IF(RADIUS+HN) 500,500,600
54 CONTINUE
55 X=CONST1*(H-(RA0(US-HC1)/TN
56 GO TO 700
57 CONTINUE
58 A=CONST1*(H-H0)
59 TO=TN*CONST1*(HC-HN)*(OMG)/GAMMA
60 X=A/TO
61 CONTINUE
62 Y=-X/GAMMA
63 IF(ONEG.EQ.0.) GO TO 800
64 IF(1.0-ONEG*Y) HQ3,803,400
65 IF(1.0-(1.0-ONEG*Y))800,800,300
66 OMEGA=1.-((1.-ONEG*Y)**(-1./ONEG)
67 RETURN
68
69 800 CONTINUE
70 IF(Y-LT.(-30.0))Y=C.0
71 OMEGA=1.-OEXP(Y)
72
73
74
75
76
77
78
79
80
81
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```

C      IF (ABS(Y) .GT. 25.0) PRINT I, Y, X, GAMMA, A, I, TN, H, HO, HN,
1      CONSTI
1      FORMAT (1H, 5E10.8)
1      IF (ABS(Y) .GT. 25.0) GO TO 10
OMEGA=1.0- EXP(Y)
10 CONTINUE
RETURN
801 WRITE(6,802)
802 FORMAT(1X,8H GAMMA=)
803 WRITE (6,804) ONEG,X,Y, GAMMA
804 FORMAT(* 80J800 *, 4E20.8)
      WRITE (6,11) H,H0,HN,TN,CONSTI,RADIUS ,A,TO,X
11 FORMAT (1H, 4E20.8)
RETURN
END
SUBROUTINE OPT1(HO,H,TO,GAMMA,RHO,CMEGA,AIRM)
SUBROUTINE TO COMPUTE OPTICAL AIRMASS
THIS ROUTINE COMPUTES AIR MASS WITHIN ONE STRATA
COMMON G , AIRW , RSTAR , RADIUS , CONSTI
RAO=RADIUS-HO
XK=CONSTI*RAL/(TO*GAMMA)
SMALLH=(H-HO)/(RADIUS-HO)
ONEH=1.0-SMALLH
ONEG=GAMMA-1.0
XK2=1.0-ONEG*SMALLH*XK)/ONEH
      COMPUTE U AND V SERIES
SUMU=0.0
SUMV=0.0
XM=0.0
DENOM=1.0
TERMU=1.0
TERMV=1.0
TEST=.00000001/(XK*GAMMA)
KOUNT=0
1000 CONTINUE
      KOUNT=KOUNT+1
      XM=XN+1.0
      DENOM=DENOM+ONEG
      FACT=XN/XK*DENOM
      TERMU=TERMU*FACT
      TERMV=TERMV*FACT*XK2
      SUMU=SUMU+TERMU
      SUMV=SUMV+TERMV
      IF (KOUNT-31) 1040,1040,1080
1040 IF (ABS(TEST)-ABS(TERMV)) 1050,1050,1050
1050 IF (ABS(TEST)-ABS(TERMU)) 1050,1050,1075
1075 IF (KOUNT-30)
1080 WRITE (6,1085)
1085 FORMAT(17H 8C0800 IN OPT1)
C
C      THIS IS A SERIES APPROXIMATION TO THE INTEGRAL FOR THE AIRMASS.
C
1100 AIRM=(RADIUS**2/RAL)*RHO*(SUMU-(1.0-OMEGA)*SUMV/ONEH)
RETURN
OPT10060
OPT10070
OPT10080
OPT10090
OPT10100
OPT10110
OPT10120
OPT10130
OPT10140
OPT10150
OPT10160
OPT10170
OPT10180
OPT10190
OPT10200
OPT10210
OPT10220
OPT10230
OPT10240
OPT10250
OPT10260
OPT10270
OPT10280
OPT10290
OPT10300
OPT10310
OPT10320
OPT10330
OPT10340
OPT10360
OPT10380
OPT10390
OPT10400
OPT10410

```

OPT10420

```

END
FUNCTION ASINX(X)
Z=X**2
ASINX=X*(1.+Z/6.+*.C75*Z**2)
RETURN
END
SUBROUTINE ZCOMPIZ(ZS,HQ,HS,US,DELZ,THETA)

```

ASTN0180  
ZCOM0050  
ZCOM0020  
ZCOM0030  
ZCOM0040  
ZCOM0060  
ZCOM0080  
ZCOM0090  
ZCOM0100  
ZCOM0110  
ZCOM0120  
ZCOM0130  
ZCOM0140  
ZCOM0150  
ZCOM0160  
ZCOM0170  
ZCOM0180  
ZCOM0190  
ZCOM0200  
ZCOM0210  
ZCOM0220  
QUAD0020

```

      THIS SUBROUTINE COMPUTES ZS

COMMON G , AIRWT , RSTAR , RADIUS , CONST1
SMALLH=(HS-H0)/(RADIUS-H0)
ONEH=1./J-SMALLH
TWOH=SMALLH*(2.-SMALLH)
C=COS(ZG)
S=SIN(ZG)
CONE=C*ONEH
CPLUS=CONE**2+TW.H
DEL2=S*(US-TWOH)
DEL3=SQRT(1.-DEL2)*(CONE+SQRT(CPLUS-US))
DEL=S*TWOH/(CONE+SQRT(CPLUS))
DELZ=ASINX(DEL2/DEL3)
ZS=Z0+DELZ
THETA=ASINX(DEL)
RETURN
END

```

QUAD0030  
QUAD0040  
QUAD0050  
QUAD0060  
QUAD0070  
QUAD0080  
QUAD0150  
QUAD0160  
QUAD0170  
QUAD0180  
QUAD0190

```

SUBROUTINE QUAD(THETA,Z0,HQ,T,GAMMA,E0,SUM,VALM)
SUBROUTINE QUAD(THETA,Z0,HQ,T,P,GAMMA,E0,SUM,VALM,PBAR)
SUBROUTINE QUAD(THETA,Z0,HQ,T,P,GAMMA,E0,SUM,VALM,PBAR,TBAR)
DIMENSION VALUEA(6)
DIMENSION VARCOM(50)
DIMENSION HINT(6)
DIMENSION XPTS(6),THPTS(6),WGHTS(6),VALUES(6)
DIMENSION XPNTS(6)
DIMENSION WGT(6)
COMMON VARCOM
EQUIVALENCE (VARCOM(1),G), (VARCOM(12),AIRWT), (VARCOM(3),
1 RSTAR), (VARCOM(4),RADIUS), (VARCOM(5),CONST1), (VARCOM(6),
2 XPTS), (VARCOM(12),WGHT), (VARCOM(18),FAKE)
EQUIVALENCE(XPTS,XPNTS)
EQUIVALENCE(WGT,WGHTS)
EQUIVALENCE(VARCOM(19),RHQ)
EQUIVALENCE (VARCOM(20),REFAM)
EQUIVALENCE (VARCOM(20),REFAM)
FCNA(0000FL)=(1.-0.0000FL/2.0)*(1.0+2.0*0000FL*(1.0+0000FL/2.0)/3.0
1)/(1.0+0000FL)**2
FCNR(0001FL)=2.-0.0001FL*(1.0+0001FL/2.0)/3.0
FCNU(0002FL,0003FL,0004FL,0005FL)=2.0*0004FL*0005FL*(1.0+000
103FL*0005FL)
FCNH(0008FL,0009FL)=2.0*SIN(0008FL/2.0)*2.0*(0009FL)*SIN(0008FL)QUAD0260
SMALLR=RADIUS+HQ*H0**2/(RADIUS-HQ)
VALC=RHQ*SMALLR*SIN(ZG)*THETA/REFAM
A=FCNA(10)
B=FCNB(10)
DO 1000 I=1,6
THPTS(I)=THETA*(.5+XPNTS(I))
HINT(I)=FCNH(THPTS(I),Z0)
1000 CONTINUE
DO 2000 I=1,6
CALL CH(HINT(I),H,FAKE,T,GAMMA,MEGA,DUMMY)
U=FCNU(A,B,E0,OMEGA)

```

C C 149

QUAD0270  
QUAD0280  
QUAD0290  
QUAD0300  
QUAD0310  
QUAD0320  
QUAD0330  
QUAD0340



QUAD0037C

QUAD0040C

QUAD0041C

QUAD0042C

QUA00043C

QUA00044C

QUAD0045C

QUA00046C

QUA00047C

```

ARG1=1.-U/CCSIZC-TH(PIS(I))*2
VALUES(I)=1./SQRT(ARG1)
VALUEA(I)=VALUES(I)*[1.-JMEGA]*SQRT(1.-U)/SINIZO-TH(PIS(I))*2
2000 CONTINUE
SUM=0./J
VALM=0.
DO 3000 I=1,6
  SUM=VALUES(I)*WGHTS(I)+SUM
  VALM=VALM+VALUEA(I)*WGHTS(I)
3000 CONTINUE
SUM=SUM*THETA
VALM=VALM*VALM
PBAR = VALM*P
TBAR = VALM*T
RETURN
END
SUBROUTINE GETT(H1,H2,P1,P2,T1,T2)
COMMON G,AIRWT,RSTAR,RADIUS,CNST1
IF(T2.GT.0.) GO TO 1700
K=0
X=P2/P1
XL=ALOGIX)
A1=CONST1*(H2-H1)/T1
CRIT=EXP(-A1)
A1=1./A1
IF(ABSIX-CRIT).GT..000001) GO TO 1000
T2=T1
RETURN
1000 XC=A1*XL+ALOGIA1)
ACRIT=-1./XL
A2=.0000011
IF(A1.LT.ACRIT) A2=A2+ACRIT
1100 F=A2*XL+ALOG(A2)-XC
FP=XL+1./A2
A3=A2-F/FP
IF(K.LT.3) GO TO 1200
IF(ABSIA3-A2).LT..0000001) GO TO 1300
1200 A2=A3
K=K+1
GO TO 1100
1300 T2=T1*A2/A1
RETURN
1700 IF(T1.EQ.T2) GO TO 1800
P2=P1*(T2/T1)*[1.-CNST1*(H2-H1)]/(T1-T2))
RETURN
1800 P2=P1*EXP(CNST1*(H1-H2)/T1)
RETURN
END
FUNCTION COT ( X )
COTIX)=CTS(X)/STN(X)
COT =COS(X)/SIN(X)
RETURN
END
DATA

```

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